

## 8.1 Introduction

The island of Saipan is centered at 15°12' N, 45°45' E to the north-northeast of Guam, Rota, Aguijan, and Tinian. With a total area of 118.98 km<sup>2</sup> and a coastline of 75 km, Saipan is the largest of the 14 islands of the Commonwealth of the Northern Mariana Islands (CNMI). The highest point on Saipan is 474 m at Okso' Tagpochau (for place-names and their locations, see Figure 8.1.2a, bottom panel in this section and Figure 8.2a in Section 8.2: "Survey Effort"). Nearly 90% of the human population of the CNMI resides on Saipan (U.S. Bureau of the Census 2011a), with 60% of this island's total population concentrated within 20% of the available landmass around the villages of Garapan, Chalan Laolao, Susupe, Chalan Kanoa, and San Antonio (Castro et al. 2006). Beaches, dive sites, and golf courses are scattered around Saipan, and the most easily accessed of these sites are located along the west coast with the majority of the hotel and tourist facilities on this island. All major boating access points are in the general Lagunan Garapan area. Isleta Managaha, a small island off the central west coast near the entrance to Saipan Harbor, is one of the most popular tourist destinations and is surrounded by a marine protected area (MPA). A large, flat bank extends ~ 10 km offshore from the west side of Saipan, and another bank extends from the northern area of Garapan Anchorage towards the southern shore. These 2 banks are used as the primary anchorage sites for commercial and military vessels operating in the CNMI.

### 8.1.1 History and Demographics

A brief summary of Saipan's history and political structure is presented here. The history of the Mariana Archipelago and the political structure of Saipan and the CNMI are discussed further in Chapter 1: "Introduction."

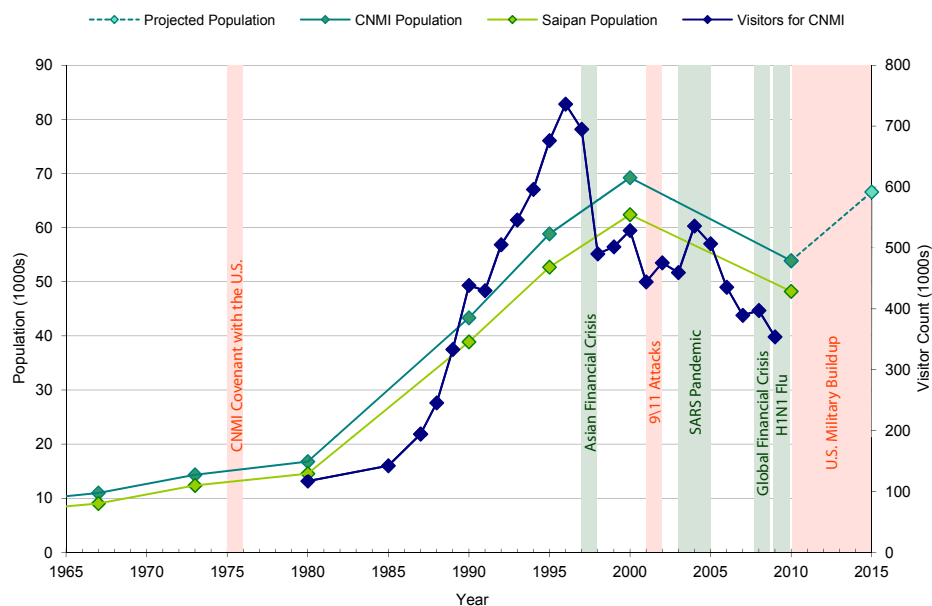
Saipan was first populated with the arrival of the Chamorro people, presumably from the Malaysian and Philippine region (Spoehr 1957), about 3500 years ago (Rogers 1995). Following European contact, the Mariana Islands were ruled by Spain from 1521 to 1899. Prolonged contact with newly introduced diseases and increased conflicts between the Chamorro and Spanish resulted in an archipelagic-wide decrease in the Chamorro population from estimates as much as 100,000 in 1668 to less than 4000 in 1710 (Rogers 1995; Underwood 1973). Chamorros remaining on Saipan and other islands were removed and resettled to Guam and Rota in 1698 (Rogers 1995). Saipan became largely uninhabited for more than 100 years until 1815. Carolinian islanders were relocated to Saipan from Lamotrek and Satawal around 1815 to provide labor, and Chamorros returned to Saipan in the late 1800s (Alkire 1984).

All of the Mariana Archipelago, except for Guam, was ruled by Germany from 1899 until 1914. Following World War I, the Northern Mariana Islands became a protectorate of Japan from 1914 to 1945. Saipan was a major sugarcane farming and processing center from the 1920s until World War II (WWII). In the summer of 1944, the U.S. military landed in Saipan with a large invasion force and simultaneously attacked a nearby Japanese fleet. Fierce land battles were fought on Saipan with heavy losses on both sides over a period of a little more than 3 weeks beginning with landings on June 15, 1944. The U.S. Navy and Air Force fired an estimated 180,000 shells on Saipan over a period of 2 days alone (Pratt 1948).

After WWII, Saipan was administered on behalf of the United Nations by the U.S. Navy and then the Department of the Interior as one of the islands included in the Trust Territory of the Pacific Islands. From 1949 to 1962, the Central Intelligence Agency restricted access to the northern half of Saipan and used this area to train foreign agents (Rogers 1995). As described in Chapter 1: "Introduction," the CNMI gained status as a commonwealth of the United States in 1976, and citizens of the CNMI received U.S. citizenship in 1986 (U.S. Department of the Interior 2009b).

In 2010, Saipan had a population of 48,220 persons, a 23% decrease from 62,392 in 2000 but a 231% increase from 14,549 in 1980 (Fig. 8.1.1a; U.S. Bureau of the Census 1983, 2011a).

**Figure 8.1.1a.** Population growth (U.S. Bureau of the Census 1983, 2003, 2011a; CNMI Department of Commerce 2002a; Secretariat of the Pacific Community 2011) and visitor count (Bank of Hawaii 1995; Lucas 1990; U.S. Department of the Interior 1996; CNMI Department of Commerce 2002b; Marianas Visitors Authority) trends on Saipan and in the CNMI during the period of 1965–2015.



### 8.1.2 Land Use

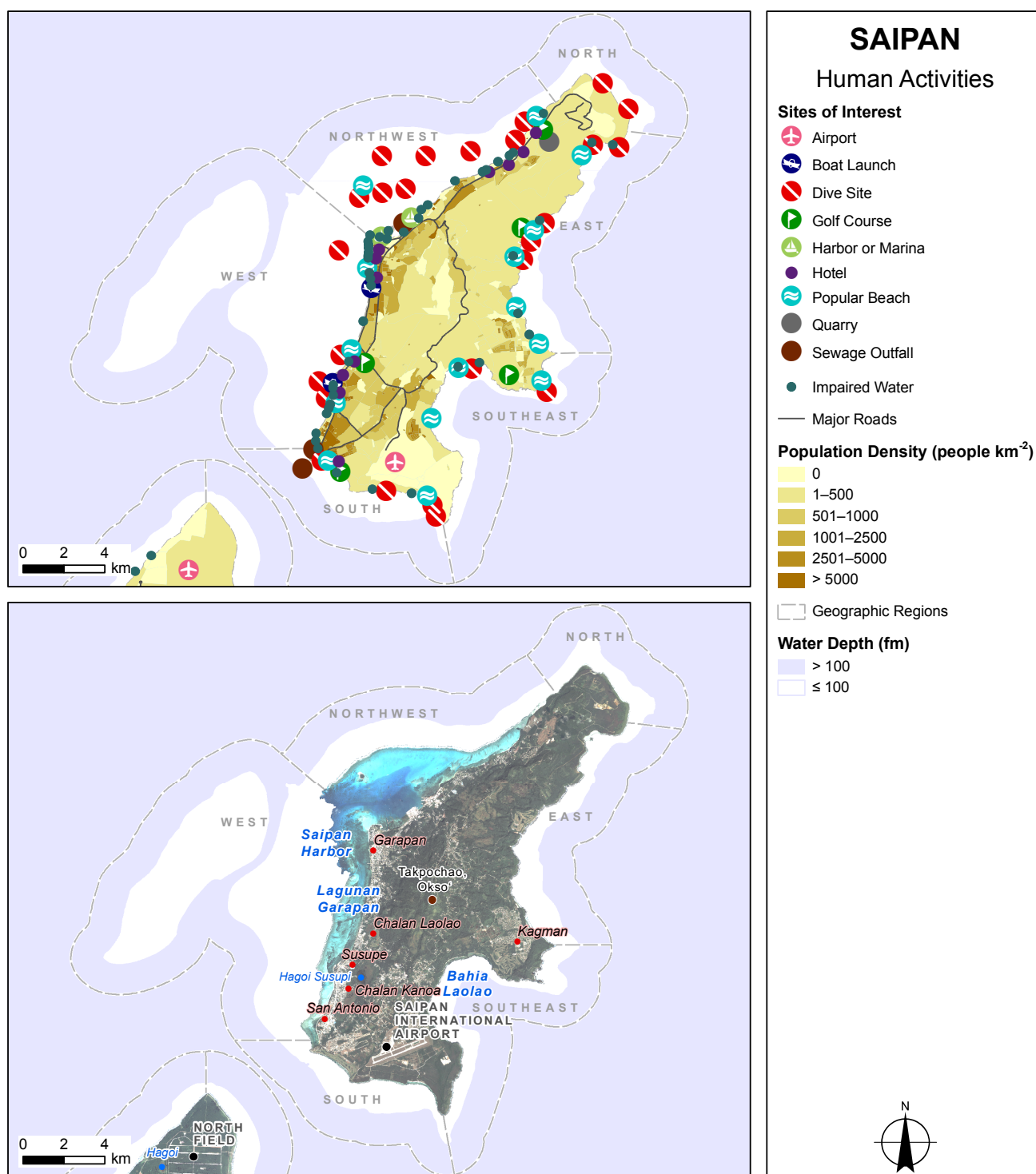
The major population centers on Saipan are primarily located along the western coastline, in the south near Saipan International Airport, and within the Kagman Peninsula (Fig. 8.1.2a). Approximately 15% of Saipan is designated as public land, and commercial and residential holdings account for 20% and 35% of land use. The remaining 30% consists of unused grassland, secondary forest, or isolated regions of primary forest (Carruth 2003). Small areas of agricultural land are scattered in the southern part of this island. A major project to restore the Bahia Laolao watershed was proposed and funded in 2009 as part of the American Recovery and Reinvestment Act (Rodriquez 2009).

The native vegetation of Saipan has been highly disturbed over the last 300 years. The thickets of native limestone forest believed to have covered this island in the late 1700s and 1800s were mostly cleared in the 1920s by the Japanese to plant sugarcane. During WWII, sugarcane plantations were abandoned, and bombing, fires, and military reconstruction further reduced the native limestone forest. Today, the introduced, low-lying tangantangan tree (*Leucaena glauca*) has replaced both the sugarcane fields and native limestone forest areas on Saipan (Liu and Fischer 2006). Small remnants of native forest remain along steep, low-elevation slopes of the Saipan Upland Mitigation Bank and the Kagman Wildlife Conservation Area (Mueller-Dombois and Fosberg 1998).

Most of the CNMI's wetlands were filled for agricultural use during the Japanese occupation associated with WWII and, more recently, for urban development. Wetlands presently make up < 5% of land in the CNMI, and only an estimated 36% of the original wetlands of the CNMI still exist (Castro et al. 2006). Hagoi Susupi, a small (0.17 km<sup>2</sup>), brackish lake near the southwest part of Saipan, is surrounded by an extensive marsh area of 2.02 km<sup>2</sup>. This marsh area accounts for 60% of the wetlands in the CNMI (Stinson 1993) and provides 77% of the remaining habitat for the Mariana common moorhen (*Gallinula chloropus guami*), a bird listed both Federally as an endangered species (U.S. Fish and Wildlife Service) and locally as a threatened or endangered species (Berger et al. 2005). The wetland surrounding Hagoi Susupi is also important for both groundwater discharge and flood control. The condition of this marsh area has been affected by wastewater from a sugar mill during the period of Japanese control (1914–1944) and by the introduction of the mosquitofish (*Gambusia affinis*) for mosquito control during WWII and of tilapia (Cichlidae) for aquaculture in the 1950s; both of these fishes are well known for their negative environmental effects (Stinson 1993). Currently, the greatest threats to Hagoi Susupi and its surrounding wetland are development and drawdown for water use.

Five MPAs have been established around Saipan, with 2 of them specifically designated for focal species. The Bahia Laolao Sea Cucumber Reserve was designated in 2000 and the Lighthouse Reef Trochus Reserve, for the conservation of mother-of-pearl shells, in 1982 (Fig. 8.1.3a, top panel). In 2001, 2 no-take marine conservation zones were designated: Bird Island Marine Sanctuary and Forbidden Island Marine Sanctuary. A third no-take zone, Managaha Marine Conservation Area, which is also a popular tourist attraction, was first designated in 2000, but lack of funds meant that enforcement of no-take policies did not begin in earnest until 2002 (Starmer et al. 2008; Wood 2007).

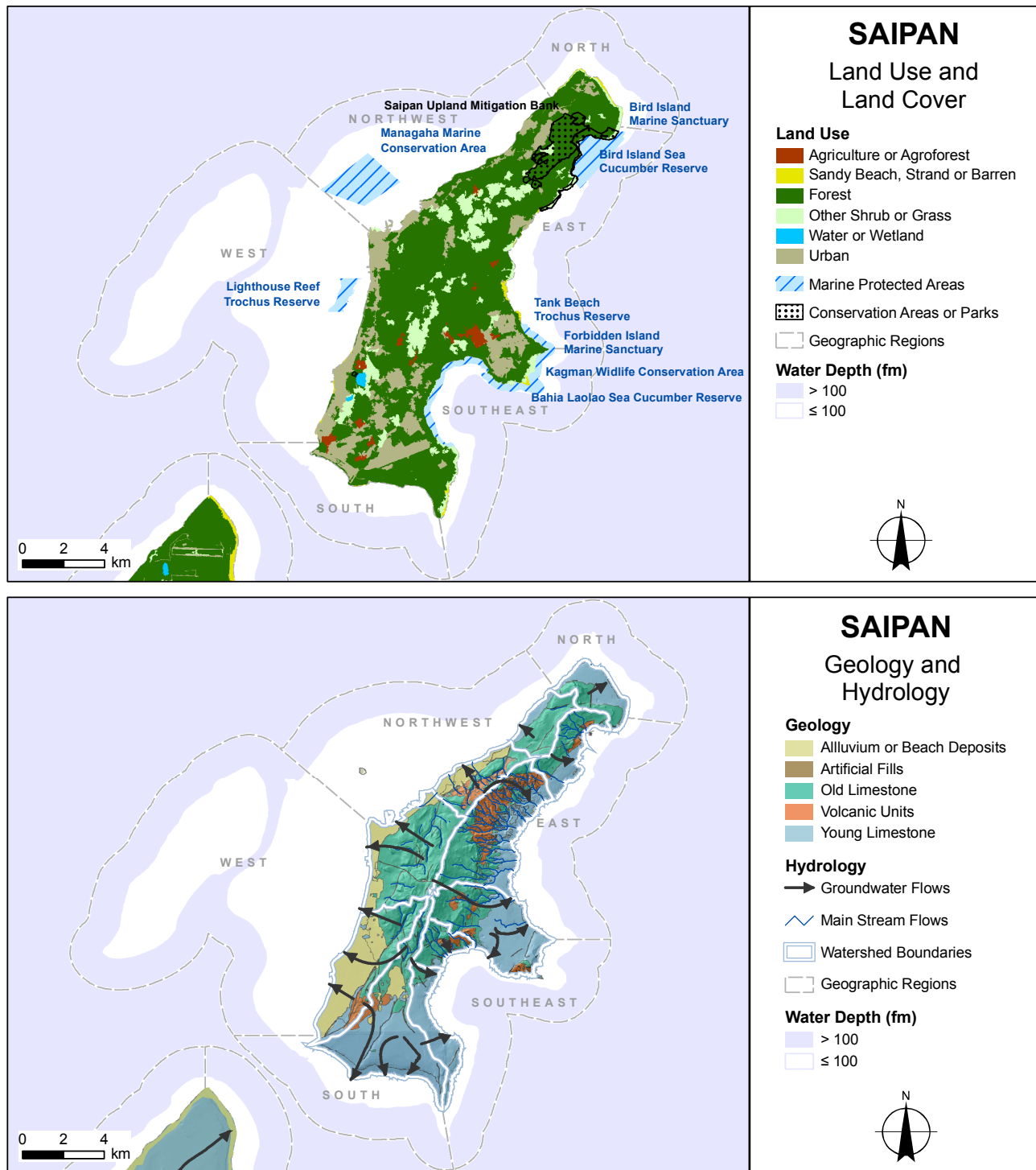




**Figure 8.1.2a.** Major locations of human activities (*top*) on Saipan that have the potential to affect the marine environment (Place-names.com; Marianas Visitors Authority; Bearden 2008; J Starmer, CNMI Coastal Resources Management Office, pers. comm.; U.S. Geological Survey 2005b) are represented over a population-density map (U.S. Bureau of the Census 2003, 2008). Satellite imagery of Saipan (*bottom*, includes material © 2006 DigitalGlobe Inc. All rights reserved), labeled with places of interest (U.S. Geological Survey).

### 8.1.3 Geography

Uplifted limestone terraces constitute the primary rock formations on Saipan, as they do on other southern islands in the Mariana Archipelago (Fig. 8.1.3a, bottom panel). Saipan is composed of 3 major limestone units: Tagpochau Limestone, which comprises the oldest limestone from 15–23 million years ago (early Miocene epoch); Mariana Limestone, from the younger Pliocene epoch (2–5 million years ago), and the Tanapag Limestone, the youngest terrace deposits from the



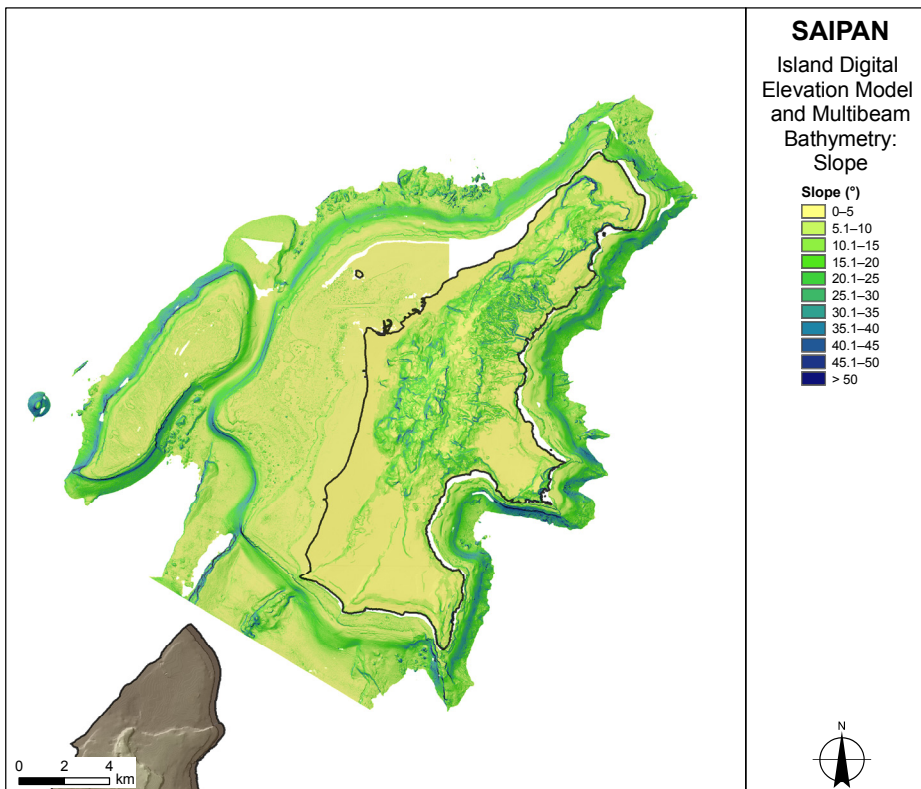
**Figure 8.1.3a.** Land use (U.S. Department of Agriculture Forest Service 2006b), conservation areas and parks (K Herrmann, CNMI Division of Environmental Quality, pers. comm.), and MPAs (NOAA Marine Protected Areas Center 2008) on Saipan are represented over a vegetation cover map (*top*, Liu and Fischer 2006). Geology, watersheds, main stream flows, and groundwater flows on Saipan (*bottom*, Carruth 2003; M Pangelinan, CNMI Department of Land and Natural Resources, pers. comm.; U.S. Geological Survey 2005a).

Pleistocene-Holocene epoch (0–2 million years ago; Riegl et al. 2008; Fig. 8.1.3a). A varied layer of thin to moderately thick limestone-derived soils—composed of clays, clay loams, and loams—is also largely present around Saipan. Other limestone areas exhibit karst topographies, which are formed by dissolution of carbonate rocks and characterized by sinkholes, caves, and subterranean passages. A well-known dive site, known as “the Grotto”, is found in a large sinkhole that connects to the ocean through several subterranean passages.

In contrast to the features around the islands of Tinian and Rota (see Chapters 7 and 5), the coastal areas of Saipan do not have high, continuous seacliffs, especially on the west (leeward) side, as shown in the combined onshore-offshore slope map (Fig. 8.1.3b). Instead, a coastal plain is inshore of the 2 large, submerged banks to the west of Saipan. A number of volcanic areas are scattered from north to south but mostly occur on the east side of this island, where basement rock with ages estimated at ~ 41 million years (Eocene) and ~ 13 million years (Miocene) is exposed (Fig. 8.1.3a, bottom panel)—covering ~ 10% of Saipan’s land area (Carruth 2003). Numerous faults transect Saipan in a north–northeast direction.

Saipan has only 3 perennial streams that together with intermittent streams, mostly on the east side, have a total length of 95.5 km as well as a lake and several isolated wetland areas (Castro et al. 2006). In 2003, Robert Carruth (2003) of the U.S. Geological Survey reported that the resources for 90% of the municipal water consumed on Saipan were 140 shallow wells fed by an average rainfall of ~ 2 m (80 in) and owned by the Commonwealth Utilities Corp. (CUC), the local municipal water utility. Castro et al. (2006) reported a total of 380 wells on Saipan, 191 of which were owned by CUC and 136 of which were owned by CUC and producing drinking water. Groundwater drainage patterns on Saipan are shown as arrows in Figure 8.1.3a, bottom panel. The largest groundwater problem in the CNMI is high chloride concentrations from saltwater intrusion into the basal aquifer, resulting from over pumping of the basal aquifer to keep up with the increasing demand (Castro et al. 2006).

Carruth (2003) reported that the chloride concentrations and rates of groundwater production from CUC’s 140 wells were not adequate for providing Saipan residents and visitors with a 24-hour supply of potable water. However, by late 2008, after improvements in storage capacity, CUC said that 75% of Saipan’s residents had an uninterrupted water supply (Todeno 2008). CUC wells on Saipan do not produce enough drinking water to meet real demand because of leaks in municipal and homeowner water distribution systems, reported the CNMI Division of Environmental Quality in reports on water quality published in 2006 and 2010 (Castro et al. 2006; Bearden et al. 2010). To avoid problems with the freshwater supply on Saipan, many hotels use reverse osmosis technology to produce freshwater from deep saltwater wells (Todeno 2009), and the resulting discharge of hypersaline water is a controversial environmental issue.



**Figure 8.1.3b.** Combined slope map using the digital elevation model and multibeam bathymetric data for Saipan.

### 8.1.4 Economy

Tourism is the major economic driver on Saipan. The CNMI government is one of the main employers on Saipan. Additional sources of revenue come from the Port of Saipan and the offshore Garapan Anchorage (GlobalSecurity.org 2005). Although fishing is not considered a significant industry, local residents depend heavily on reef fishes as a food source, and fishing historically has been considered an important cultural practice.

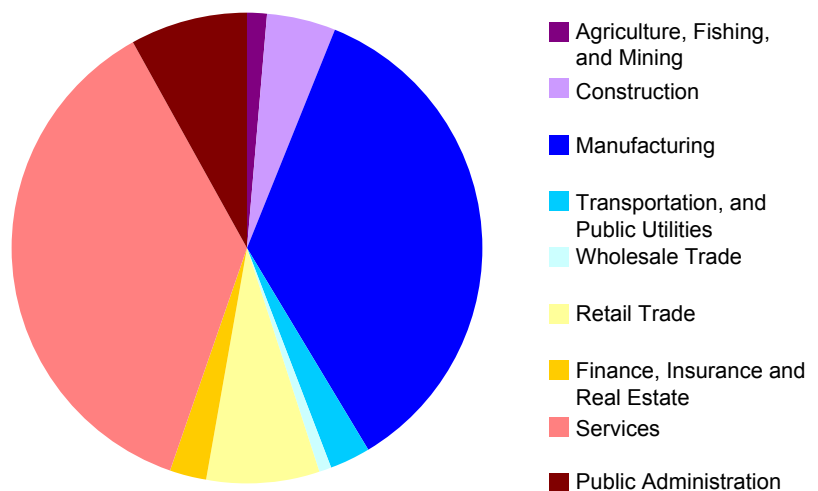
The majority of tourists to the CNMI are from Asia, led by Japan and Korea. Japanese visitors stay an average of 3.5 nights, while Koreans stay an average of 4.5 nights (Van Beukering et al. 2006). In the last few years, China and Russia have become important sources of tourism revenue (U.S. Government Accountability Office [GAO] 2008). Tourism has been negatively affected by global economic conditions; increasing competition from other, less expensive destinations; transportation shortages (flights and ferry); increasing fuel and other costs, including the rising minimum wage; and uncertainties over inclusion of Chinese and Russian visitors in the Guam-CNMI Visa Waiver Program.

The only industry to equal Saipan's tourism industry was the garment industry. Started on Saipan in 1983, the garment industry was once a unique catalyst for Saipan's economy (Fig. 8.1.4a). Gross receipts for this industry peaked in 1998 with more than \$1 billion (GAO 2000). The garment industry in 1998 paid \$52 million in taxes and fees, accounting for more than 22% of the CNMI government's \$234 million in total general fund revenue (GAO 2000). Recent changes in World Trade Organization quotas and U.S. minimum wage and immigration laws significantly reduced the revenue from and number of garment factories in the CNMI until the last garment factory on Saipan closed in February 2009. Garment exports decreased in value from \$826 million in 2004 to \$3 million in 2009 (CNMI Department of Commerce 2006, 2010).

The garment factories on Saipan had been able to send "Made in the U.S.A" garments into the United States duty free while using foreign workers who were paid below the U.S. minimum wage; thus, their goods were very competitive with foreign products. In 2005, the United States, in accordance with one of the 1994 World Trade Organization Uruguay Round agreements, lifted quota restrictions on garment products from other countries entering the United States, making products from the CNMI less competitive. In 2007, President George W. Bush signed into law a minimum wage bill that raised wages in the CNMI by \$0.50 an hour and requires a 9-step yearly increase to bring the CNMI minimum wage in line with the U.S. rate of \$7.25 an hour by 2015 (Vallejera 2007). In 2008, the U.S. Congress passed legislation to federalize immigration to the CNMI, which not only may have affected what remained of the garment industry but also could have considerable effect on tourism and foreign investment (GAO 2008). With no manufacturing output, container trade by 2009 had shrunk from 140 to 5 outbound containers per week (Eugenio 2009). The reduction in cargo trade and dramatic rise in fuel costs have caused a rapid increase in the price of all goods in the CNMI. The state of Saipan's economy, combined with the military buildup in Guam, is causing a migration of the workforce out of the CNMI and a shortage of education and health workers (CNMI Department of Commerce 2009).

As the main island of the CNMI, Saipan is the location for almost all major government offices. With the decline in both tourism and the garment industry, the CNMI government general fund revenues fell to \$155 million in 2009, a 29% drop from tax and fee revenues in 2004 (CNMI Department of Commerce 2006, 2010). Facing ongoing budget shortfalls, the CNMI government in 2010 cut hours and holidays for its workers and in early 2011 proposed layoffs.

**Figure 8.1.4a.** Employment by sector on Saipan in 2005 (CNMI Department of Commerce 2008), the year in which the United States lifted quota restrictions on garment products from foreign countries, making "Made in the U.S.A" garments manufactured in Saipan less competitive.

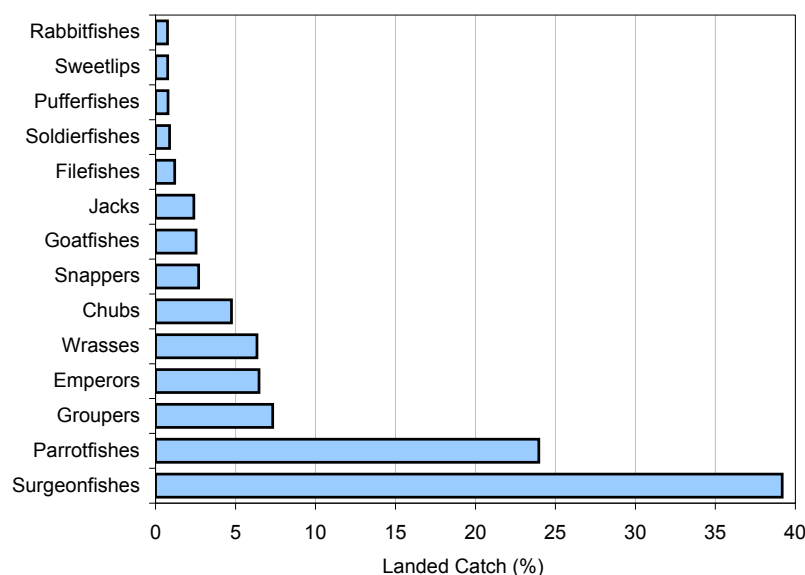


One potentially positive development for the CNMI government and Saipan is the designation in 2009 of the Marianas Trench Marine National Monument, which will be jointly managed by the Department of the Interior, NOAA, and the CNMI. This development could have positive effects on tourism and the economy, including new employment opportunities on Saipan, if and when a Monument office is located there.

The chief domestic commercial fishery in the CNMI is a small-boat, 1-d, troll fishery, and most boats are outboard-powered, runabout-type vessels of 12–24 ft. In addition, a few larger boats are used around the islands north of Saipan, mainly for bottom fishing, and a small charter fleet exists. Trolling is the most common fishing method, but bottom fishing and reef fishing are also popular. Reef fishes not only make up a significant portion of the total commercial catch but also are an important component of the local diet (Hamm et al. 2010).

The Division of Fish and Wildlife (DFW) of the CNMI Department of Lands and Natural Resources, with technical assistance from the Western Pacific Fisheries Information Network (WPacFIN) of the NOAA Pacific Islands Fisheries Science Center, collects nearshore fisheries-dependent creel survey data on primary landing sites of Saipan. According to this survey data (DFW 2009), fishermen around Saipan targeting nearshore species typically use one of the following methods: spearing (scuba or freediving), nets, trolling, or bottom fishing. These fishermen can be based on shore or in a boat.

Spearing and netting data are reported in more detail here because these methods capture the nearshore species typically found on coral reefs. Data collected from the creel surveys for the period of 2006–2008 were extrapolated to include data gaps and estimates of total catch with assistance from WPacFIN. Similar to findings from creel surveys around Guam, boat-based spearfishermen around Saipan mostly captured surgeonfishes (Acanthuridae) and parrotfishes (Scaridae) with 39% and 24% of landed catch by weight (Fig. 8.1.4b), followed by groupers (Serranidae) and emperors (Lethrinidae) with 7% and 6% of landed catch by weight. Gillnet landings were composed of jacks (Carangidae, mostly bigeye scads), emperors, and surgeonfishes with 49%, 21%, and 20% of landed catch by weight.



**Figure 8.1.4b.** Family composition of the landed catch of spearfishermen, by weight as a proportion of total catch weight, around Saipan during the period of 2006–2008 (DFW 2009). Data were collected from boat-based creel surveys conducted by the CNMI DFW and extrapolated to total catch data with assistance from the WPacFIN.

### 8.1.5 Environmental Issues on Saipan

A number of environmental issues and concerns that could influence the reefs around Saipan have been raised and reported in agency documents (Starmer et al. 2008, 2005; CNMI Department of Commerce 2009):

- Nonpoint source pollution is recognized as the main anthropogenic stressor on Saipan and comes from many diffuse sources:
  - Eroding badlands
  - Unpaved road runoff into Bahia Laolao
  - Beach traffic of off-road vehicles
  - Runoff during storms



- Point source pollution sources:
  - o Sewage outfalls
  - o Discharge of hypersaline and nutrient-enriched wastewater from reverse osmosis water purification systems, now pumped into deep injection wells with unknown long-term effects
  - o Nutrient discharge from golf courses and agriculture
- Deterioration of power and wastewater infrastructure
- Damage from the Puerto Rico dump, which the Environmental Protection Agency (EPA) mandated to be closed
- Climate change and related effects:
  - o Coral bleaching
  - o Ocean acidification
  - o Shoreline change, especially on Isleta Managaha
  - o Coral disease, resulting from the previously noted effects
- Damage from boating and recreational activities:
  - o Anchoring at dive sites
  - o Jet ski activities
  - o Anchoring of pre-positioned ships in Saipan Harbor and Garapan Anchorage
  - o Wrecked and abandoned vessels
  - o Marine debris from fishing gear
- Pressure on coral reef fisheries from human activities:
  - o Degraded reef habitat
  - o Local declines of commercially important reef fish

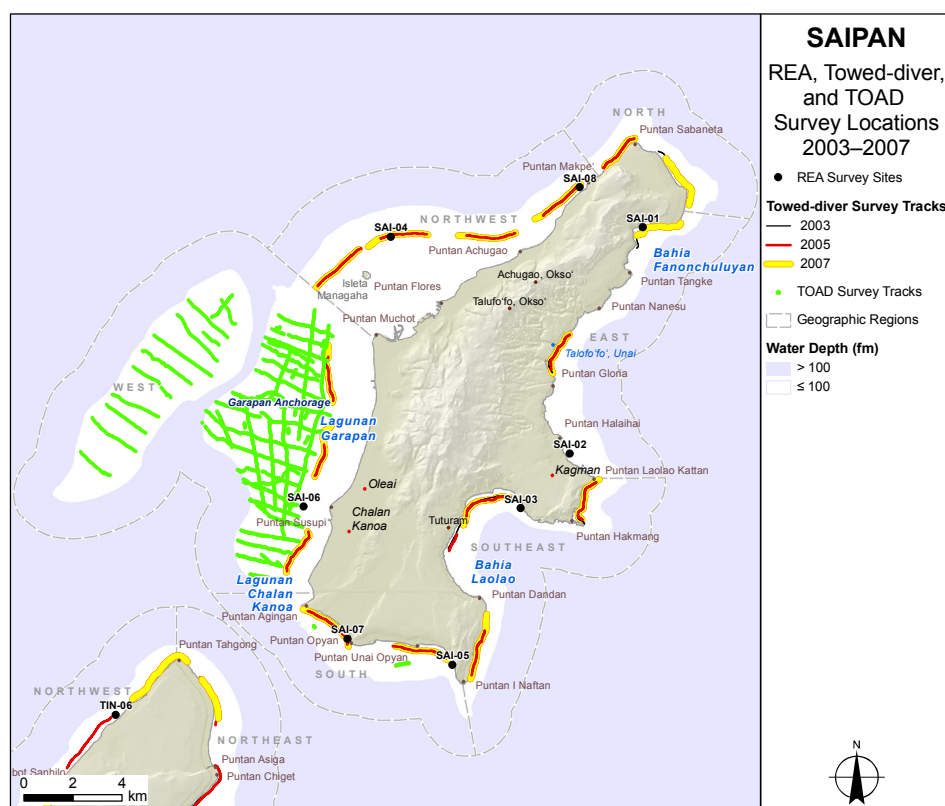
The following projects are either proposed or already underway in an effort to improve Saipan's environment (Starmer et al. 2008; CNMI Department of Commerce 2009):

- Active management of coral reefs
- Participation in the Micronesian Challenge and establishment of MPAs
- Rehabilitation of existing power generation facilities
- Development of alternate energy sources
- Rehabilitation of wastewater systems
- Expansion and upgrade of existing water infrastructure to comply with an EPA court order
- Closure of Puerto Rico dump
- Destination enhancements at Hagoi Susupi, the Marianas Trench Marine National Monument, and other areas on and around Saipan
- Resurfacing of secondary roads

## 8.2 Survey Effort

Extensive biological, physical, and chemical observations collected under the Mariana Archipelago Reef Assessment and Monitoring Program (MARAMP) have documented the conditions and processes influencing coral reef ecosystems around the island of Saipan since 2003. The spatial reach and time frame of these survey efforts are discussed in this section. The disparate areas around this island often are exposed to different environmental conditions. To aid discussions of spatial patterns of ecological and oceanographic observations that appear throughout this chapter, 6 geographic regions around Saipan are delineated in Figure 8.2a; wave exposure and breaks in survey locations were considered when defining these geographic regions. This figure also displays the locations of the Rapid Ecological Assessment (REA) surveys, towed-diver surveys, and towed optical assessment device (TOAD) surveys conducted around Saipan. Potential reef habitat around this island is represented by a 100-fm contour shown in white on this map.

Benthic habitat mapping data were collected around Saipan using a combination of acoustic and optical survey methods. MARAMP benthic habitat surveys conducted with multibeam sonar around Saipan, Marpi Bank, Tinian, Tatsumi Reef, and Aguijan covered a total area of 213.4 km<sup>2</sup> in 2003 and 1800 km<sup>2</sup> in 2007. Optical validation and habitat characterization were completed using towed-diver and TOAD surveys that documented live coral cover, sand cover, and habitat complexity. The results of these efforts are discussed in Section 8.3: "Benthic Habitat Mapping and Characterization."



**Figure 8.2a.** Locations of REA, towed-diver, and TOAD benthic surveys conducted around Saipan during MARAMP 2003, 2005, and 2007 and TOAD surveys conducted in 2004. To aid discussion of spatial patterns, this map delineates 6 geographic regions: north, east, southeast, south, west, and northwest.

Information about the condition, abundance, diversity, and distribution of biological communities around Saipan was collected using REA, towed-diver, and TOAD surveys. The results of these surveys are reported in Sections 8.5–8.8: “Corals and Coral Disease,” “Algae and Algal Disease,” “Benthic Macroinvertebrates,” and “Reef Fishes.” The numbers of surveys conducted during MARAMP 2003, 2005, and 2007 and in 2004 are presented in Table 8.2a, along with their mean depths and total areas or length.

**Table 8.2a.** Numbers, mean depths (m), total areas (ha), and total lengths (km) of REA, towed-diver, and TOAD surveys conducted around Saipan during MARAMP 2003, 2005, and 2007 and TOAD surveys conducted in 2004. REA survey information is provided for both fish and benthic surveys, the latter of which includes surveys of corals, algae, and macroinvertebrates.

Survey Type	Survey Detail	Year		
REA		2003	2005	2007
Fish	Number of Surveys	5	8	8
	Mean Depth (m)	12.7 (SD 1.4)	12.8 (SD 1.5)	12.8 (SD 1.5)
Benthic	Number of Surveys	6	8	8
	Mean Depth (m)	13.1 (SD 1.6)	12.8 (SD 1.5)	12.8 (SD 1.5)
Towed Diver		2003	2005	2007
	Number of Surveys	6	17	16
	Total Survey Area (ha)	11.8	32.3	37.0
	Mean Depth (m)	11.4 (SD 1)	14.9 (SD 1.7)	14.9 (SD 1.4)
TOAD		2003	2004	
	Number of Surveys	13	41	
	Total Length (km)	4.39	136.26	

Spatial and temporal observations of key oceanographic and water-quality parameters influencing reef conditions around Saipan were collected using (1) a diverse suite of moored instruments designed for long-term observations of high-frequency variability of temperature, (2) closely spaced conductivity, temperature, and depth (CTD) profiles of the vertical structure of water properties, and (3) discrete water samples for nutrient and chlorophyll-*a* analyses. CTD casts were conducted during MARAMP 2003, 2005, and 2007, and water sampling was performed during MARAMP 2005 and 2007. Results from some casts and water samples are not presented in this report because either the data were redundant or erroneous or no data were produced (see Chapter 2: “Methods and Operational Background,” Section 2.3: “Oceanography and Water Quality”). A summary of deployed instruments and collection activities is provided in Table 8.2b, and results are discussed in Section: 8.4: “Oceanography and Water Quality.”

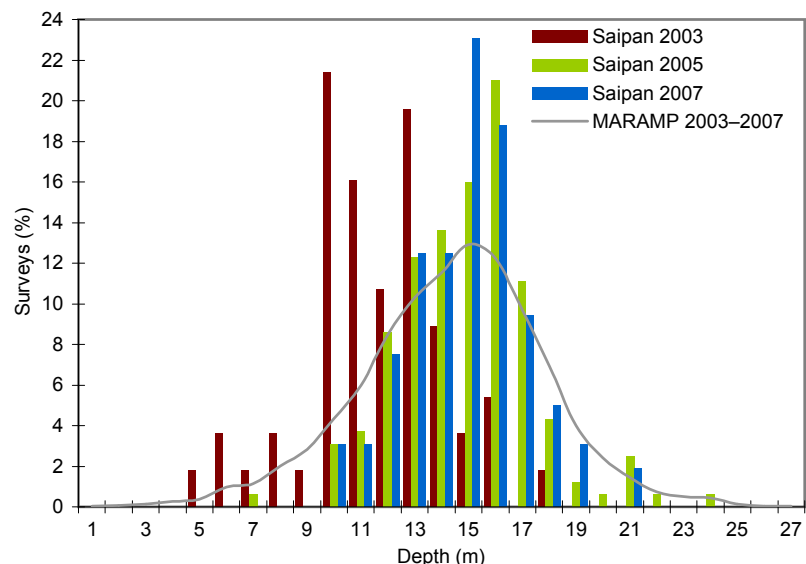
**Table 8.2b.** Numbers of oceanographic instruments deployed, shallow-water and deepwater CTD casts performed, and water samples collected around Saipan during MARAMP 2003, 2005, and 2007. Four types of instruments were moored around Saipan: Coral Reef Early Warning System (CREWS) buoy, sea-surface temperature (SST) buoy, subsurface temperature recorder (STR), and ecological acoustic recorder (EAR). Shallow-water CTD casts and water samples were conducted from the surface to a 30-m depth, and deepwater casts were conducted to a 500-m depth. Additional deepwater CTD cast information is presented in Chapter 3: “Archipelagic Comparisons.”

Observation Type	Year								Lost
Instruments	2003	2004		2005		2007		2009	
	Deployed	Retrieved	Deployed	Retrieved	Deployed	Retrieved	Deployed	Retrieved	
CREWS	1	1	1	1	1	1	—	—	—
SST	—	—	—	—	—	—	1	1	—
STR	—	—	—	—	1	1	4	3	—
EAR	—	—	—	—	—	—	2	1	—
<b>CTD Casts</b>	<b>2003</b>			<b>2005</b>		<b>2007</b>			<b>Total</b>
Shallow-water Casts	20			31		38			89
Deepwater Casts	—			4		6			10
<b>Water Samples</b>				<b>2005</b>		<b>2007</b>			<b>Total</b>
				7		4			11

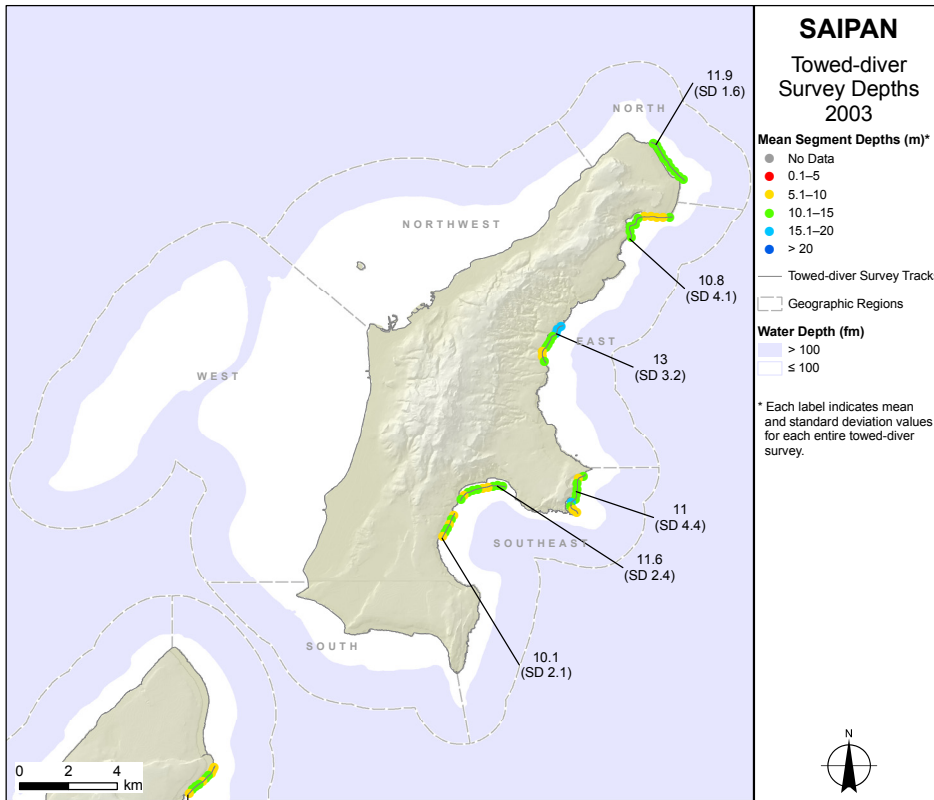
### Towed-diver Surveys: Depths

Figures 8.2b–e illustrate the locations and depths of towed-diver-survey tracks around Saipan and should be referenced when further examining results of towed-diver surveys from MARAMP 2003, 2005, and 2007.

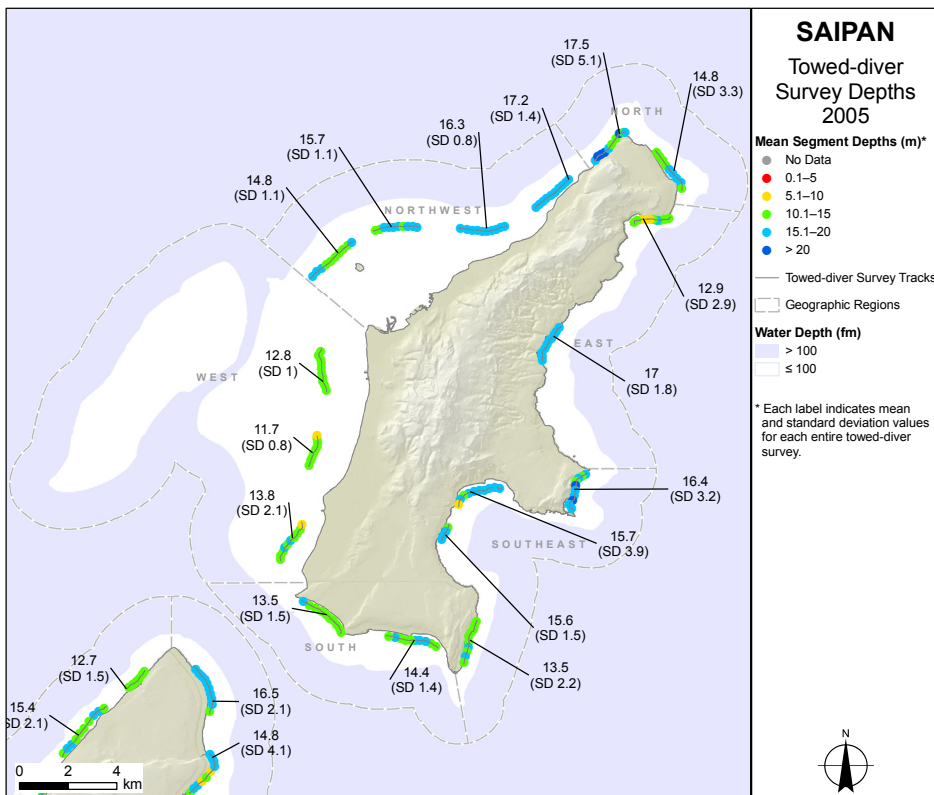
**Figure 8.2b.** Depth histogram plotted from mean depths of 5-min segments of towed-diver surveys conducted on forereef habitats around Saipan during MARAMP 2003, 2005, and 2007. Mean segment depths were derived from 5-s depth recordings. Segments for which no depth was recorded were excluded. The grey line represents average depth distribution for all towed-diver surveys conducted around the Mariana Archipelago during MARAMP 2003, 2005, and 2007.



During MARAMP 2003, 6 towed-diver surveys were conducted along parts of the forereef slopes in the north, east, and southeast regions of Saipan (Figs. 8.2b and c). The mean depth for all survey segments was 11.4 m (SD 1), and the mean depth of individual surveys ranged from 10.1 m (SD 2.1) to 13 m (SD 3.2).



**Figure 8.2c.** Depths and tracks of towed-diver surveys conducted on forereef habitats around Saipan during MARAMP 2003. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth in meters (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.

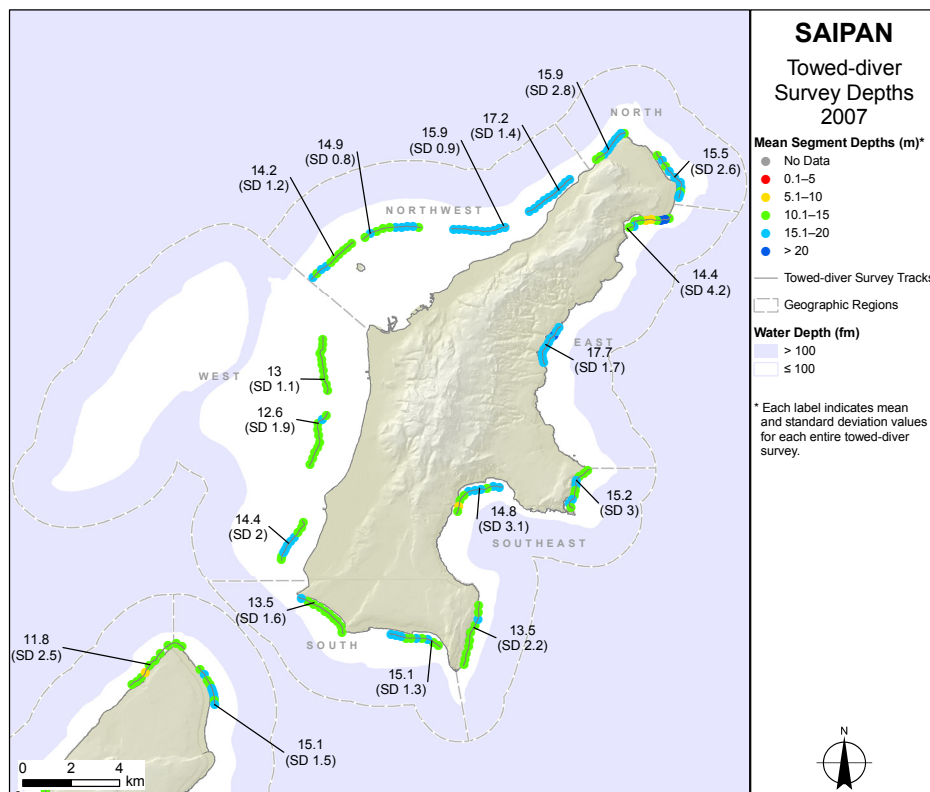


**Figure 8.2d.** Depths and tracks of towed-diver surveys conducted on forereef habitats around Saipan during MARAMP 2005. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth in meters (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.

During MARAMP 2005, 17 towed-diver surveys were conducted along the forereef slopes around most of Saipan (Figs. 8.2b and d). The mean depth for all survey segments was 14.9 m (SD 1.7), and the mean depth of individual surveys ranged from 11.7 m (SD 0.8) to 17.5 m (SD 5.1).

During MARAMP 2007, 16 towed-diver surveys were conducted along the forereef slopes around most of Saipan (Figs. 8.2b and e). The mean depth for all survey segments was 14.9 m (SD 1.4), and the mean depths of individual surveys ranged from 12.6 m (SD 1.9) to 17.7 m (SD 1.7).

**Figure 8.2e.** Depths and tracks of towed-diver surveys conducted on forereef habitats around Saipan during MARAMP 2007. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth in meters (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.



### 8.3 Benthic Habitat Mapping and Characterization

Benthic habitat mapping and characterization surveys around the island of Saipan were conducted during MARAMP 2003, 2005, and 2007 using acoustic multibeam sonar, underwater video and still imagery, and towed-diver observations. Acoustic multibeam sonar mapping provided bathymetric and backscatter data products over the depth range of ~15–1000 m around most of Saipan and to ~2800 m to the east of Saipan. Optical validation and benthic characterization, via diver observations and both video and still underwater imagery, were performed at depths < 5–200 m.

Lidar and multibeam data were also collected by the Naval Oceanographic Office (NAVOCEANO) in 2001. Data were acquired west of Saipan and, most important, included Lagunan Garapan, a large, shallow lagoon that extends between Puntans Muchot and Agingan (for place-names and their locations, see Fig. 8.2a in Section 8.2: Survey Effort).

In addition to data from the MARAMP, the Coral Reef Ecosystem Division (CRED) collected and analyzed optical data in Garapan Anchorage off the west side of Saipan (Rooney et al. 2005) through a contract with the Military Sealift Command (MSC). As part of this contract, the MSC provided funds to facilitate and accelerate the analysis of multibeam bathymetry data already collected as part of CRED's MARAMP. These efforts supported the assessment of the distribution of coral reef resources in Garapan Anchorage with the goal of minimizing impacts on coral-rich habitats from the expanded use of existing anchorage sites and proposed use of additional sites.

As a result of the MSC contract, an additional 41 TOAD surveys were conducted in 2004, covering an estimated 120 linear km of seabed. To estimate the living benthic faunal cover between survey tracks, CRED completed additional analyses of acoustic and optical data. A map showing the predicted locations of sand basins within Garapan Anchorage was



created using textural analysis of multibeam bathymetry data in combination with bathymetry-derived slope (Cutter 2004). A second analysis used the universal kriging geostatistical technique to interpolate percentage of cover of live hard corals between survey tracks and produce a map predicting percentage of coral cover across this anchorage area. The percentage of the seafloor covered by corals was assigned a value of zero in the identified sand basins. Estimates of coral cover from analyses of TOAD video include all types of corals, such as scleractinian (hard) corals, soft corals, sea fans, etc. However, more than 95% of the benthic fauna observations were of live hard corals, so the resulting map predicts distribution primarily for hard coral habitat.

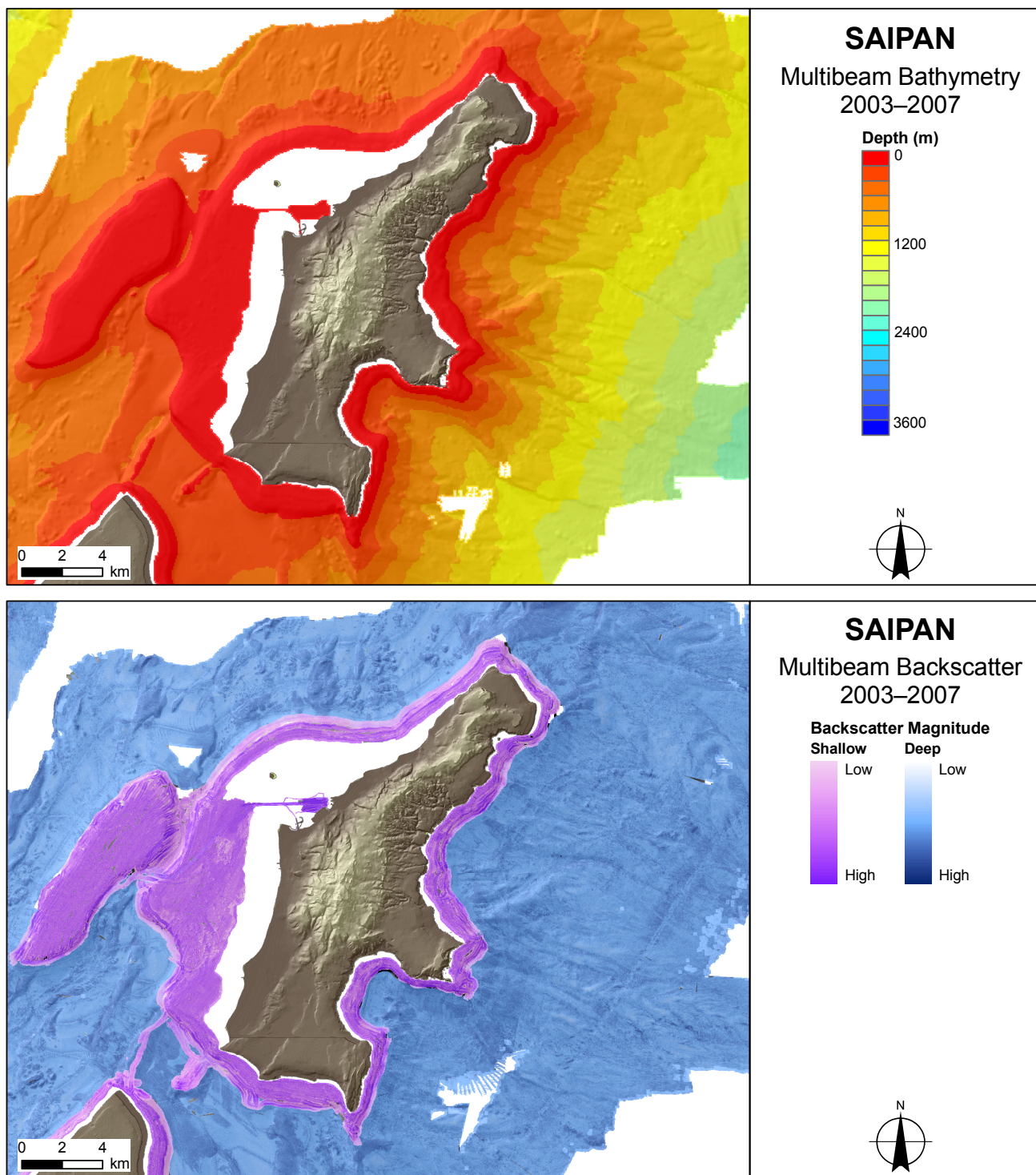
These derived map products are presented and discussed in this section in relation to optical validation data from analyses of towed-diver and TOAD surveys.

### 8.3.1 Acoustic Mapping

Multibeam acoustic bathymetry and backscatter imagery (Fig. 8.3.1a) collected by CRED around Saipan, Marpi Bank, Tinian, Tatsumi Reef, and Aguijan between 2003 and 2007 encompassed an area of 2013.4 km<sup>2</sup>. Lidar and multibeam bathymetry data collected by the NAVOCEANO around Garapan Anchorage and Lagunan Garapan in 2001 covered an additional area of 32 km<sup>2</sup> (Fig. 8.3.1b).

Bathymetry acquired around Saipan show that the seafloor on the eastern side of this island descends steeply to a depth of 300 m within 1.5 km of the shore (Fig. 8.3.1a, top panel). Almost the entire west side of this island is fronted by a 21 km long lagoon called Lagunan Garapan. Located seaward of the barrier reef forming Lagunan Garapan is an extensive shallow bank forming the largest shallow shelf in the entire Mariana Archipelago. The shelf extends as much as 6 km offshore and has a surface area of 33 km<sup>2</sup>, at depths of ~20–50 m. A narrow channel separates this shelf from a second bank of similar depth that covers 25 km<sup>2</sup>. North and east of Saipan, the bathymetry also reveals a series of canyons and ridges, running roughly eastward, that punctuate an otherwise gently deepening seabed. These canyons and ridges extend 5–10 km from the shallow shelf, ending at depths > 1000 m. On the seabed southeast of Saipan and in Bahia Laolao, the bathymetry shows debris, which may have been deposited through mass wasting, the movement of soil and surface materials by gravity. A smooth, flat channel separates Saipan from Tinian to the south, within which 2 large ridges are shown.

Backscatter data, despite some artifacts, give an indication of the roughness, hardness, and slope of the seabed around Saipan. On the shallow banks around Saipan, predominantly high backscatter values suggest that these areas may be characterized by hard substrates (Fig. 8.3.1a, bottom panel). In the deeper areas, backscatter values appear to have more variability with higher intensity backscatter values associated with major topographic features, such as the tops of ridges and areas of debris, and lower intensity backscatter values associated with the flatter areas in between.

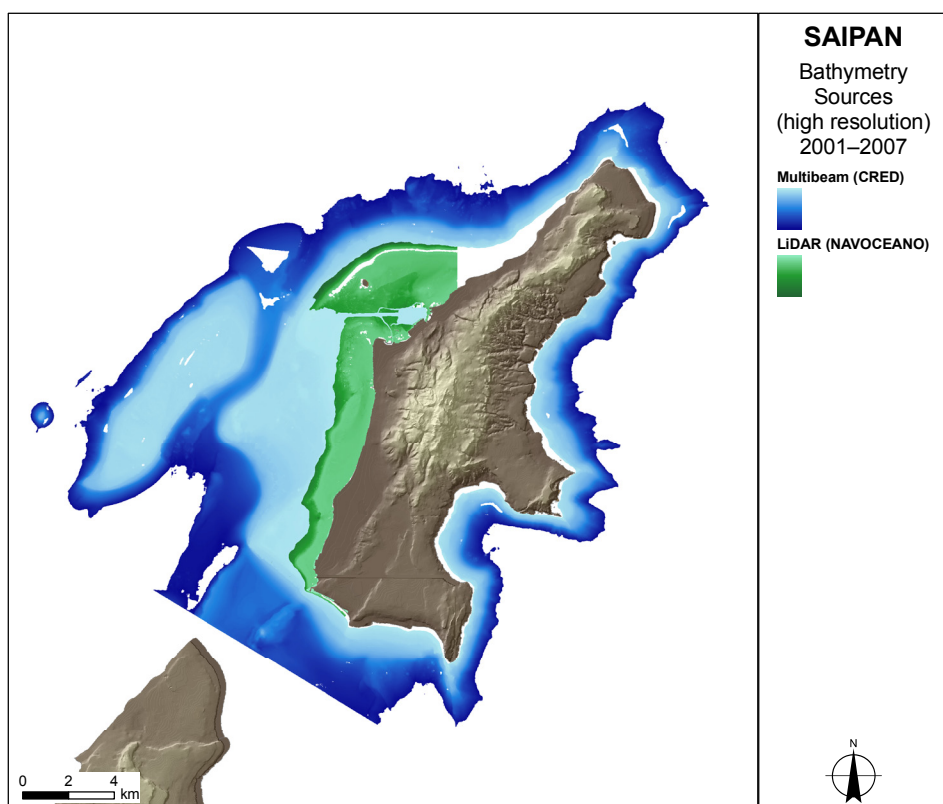


**Figure 8.3.1a.** Gridded (*top*) multibeam bathymetry (grid cell size: 60 m) and (*bottom*) backscatter (grid cell size: 5 m) collected around Saipan during MARAMP 2003 and 2007 at depths of 15–2800 m. Shallow-backscatter data (shown in purple) were collected using a 240-kHz Reson SeaBat 8101 ER sonar, and deep-backscatter data (shown in blue) were collected using a 30-kHz Kongsberg EM 300 sonar. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates, such as unconsolidated sediment. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom or coral substrates.

## High-resolution Bathymetry and Derivatives

Combined lidar and multibeam data collected by the NAVOCEANO in 2001 have recently become available for the Garapan Anchorage and Lagunan Garapan areas. NAVOCEANO lidar data will be incorporated here only in the lagoon areas not covered by CRED-collected multibeam data. A description of the combined lidar multibeam data set is provided in the NAVOCEANO Report of Survey (Naval Oceanographic Office 2001).

The final Saipan depth map is a mosaic of multibeam and lidar data from these 2 sources (Fig. 8.3.1b). Only bathymetric data, and no multibeam backscatter data, are available from these surveys; thus, only bathymetry, slope, rugosity, and bathymetric position index (BPI) zones products for Lagunan Garapan can be derived from the combined data set.



**Figure 8.3.1b.** Location of multibeam data collected by CRED (shown in blue) and lidar data collected by the NAVOCEANO (shown in green).

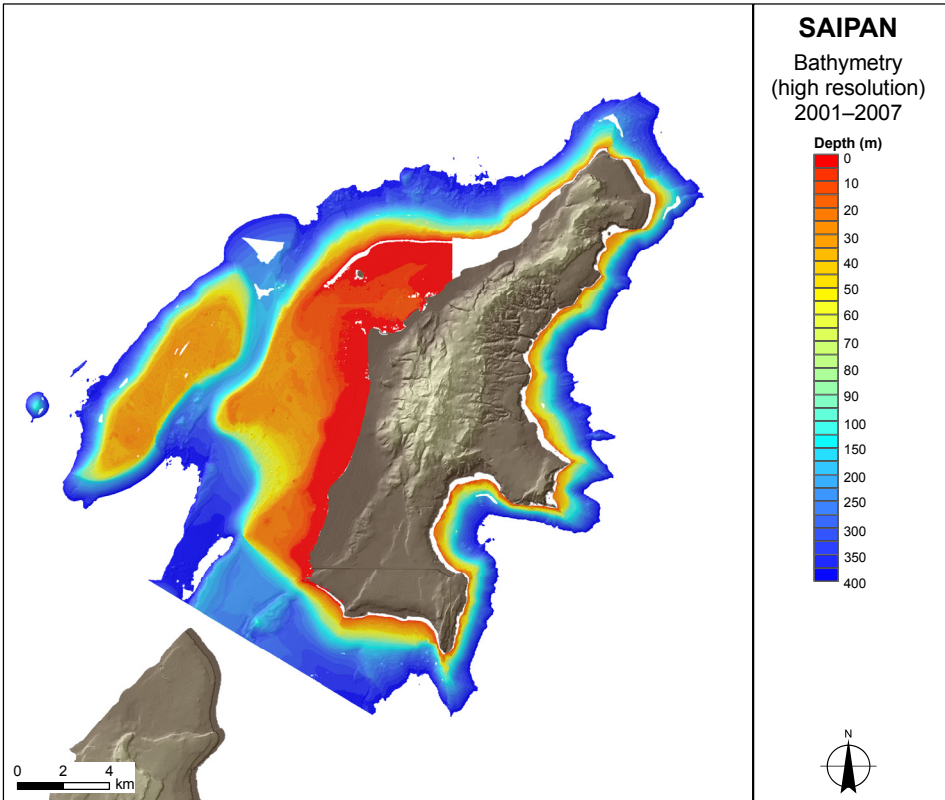
High-resolution multibeam data and NAVOCEANO lidar data collected in nearshore (depths of 0–400 m) waters around Saipan were combined into a grid at 5-m resolution to allow for the identification of fine-scaled features (Fig. 8.3.1c). These high-resolution data were used to derive maps showing slope (Fig. 8.3.1d), rugosity (Fig. 8.3.1e), and BPI zones (Fig. 8.3.1f). Together, these maps provide layers of information to characterize the benthic habitats around Saipan.

North of Saipan, the edge of a bank runs close to the coast, and depths of 300 m are reached within a few kilometers of shore. This bank edge is characterized by very steep slopes of  $> 50^\circ$ , below which the seabed slopes more gradually. A series of terraces extend away from Saipan's northeast and northwest points and may be related to previous sea level stands.

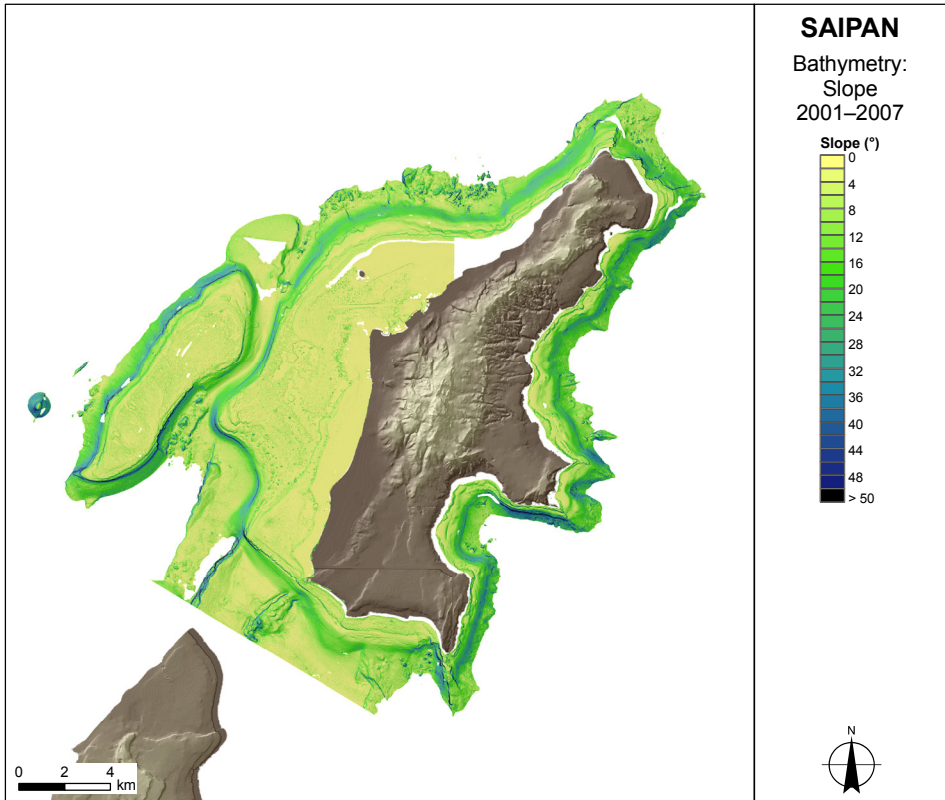
East of Saipan, a shallow bank ends within 500 m of the shore, below which the seabed forms a descending series of loosely defined terraces. On the terrace edges, high-resolution bathymetry and slope maps reveal a distinctive topographic pattern, which may be related to the presence of coral reef formations. Two major headlands on the east side of Saipan, Puntans Laolao Kattan and Hakmang, both extend into steep sided submarine ridges. These steep slopes are particularly evident at the head of the canyon between the 2 points and south of Putnan Hakmang on the north side of Bahio Laolao. BPI terrain analysis emphasizes the lack of flat seabed and highlights the influence of slope on benthic habitats in this area.



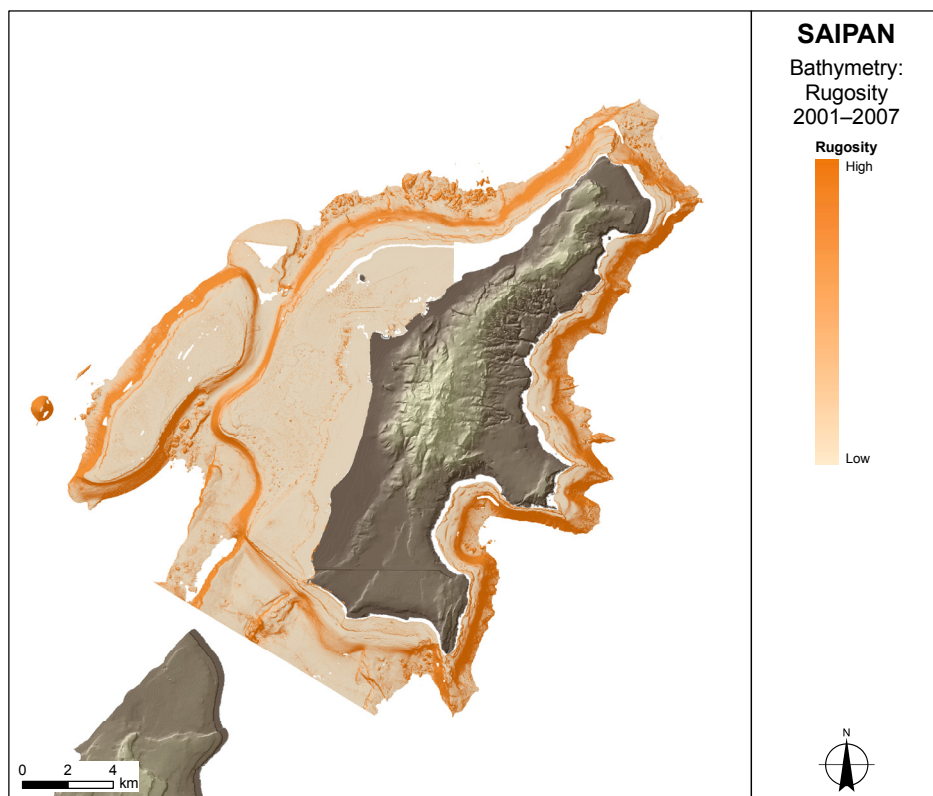
**Figure 8.3.1c.** High-resolution bathymetry collected around Saipan between 2001 and 2007. This 5-m bathymetry grid, clipped at 400 m, is used as the basis for slope, rugosity, and BPI derivatives.



**Figure 8.3.1d.** Slope (°) of 5-m bathymetric grid around Saipan. Derived from data collected between 2001 and 2007, this map reflects the maximum rate of change in elevation between neighboring cells with the steepest slopes shown in the darkest shades of blue and the flattest areas in yellow shades.



South of Saipan, slope and rugosity maps suggest that the channel separating Saipan and Tinian is characterized by very low levels of rugosity, and BPI terrain analysis suggests this channel is classified as an area of flats. The BPI and slope analyses also clearly highlight the steep ridge that crosses this channel. The top of the bank in this area is characterized by a distinctive topographic pattern of mounds and ridges, depicted in the slope, rugosity, and high-resolution bathymetry maps.



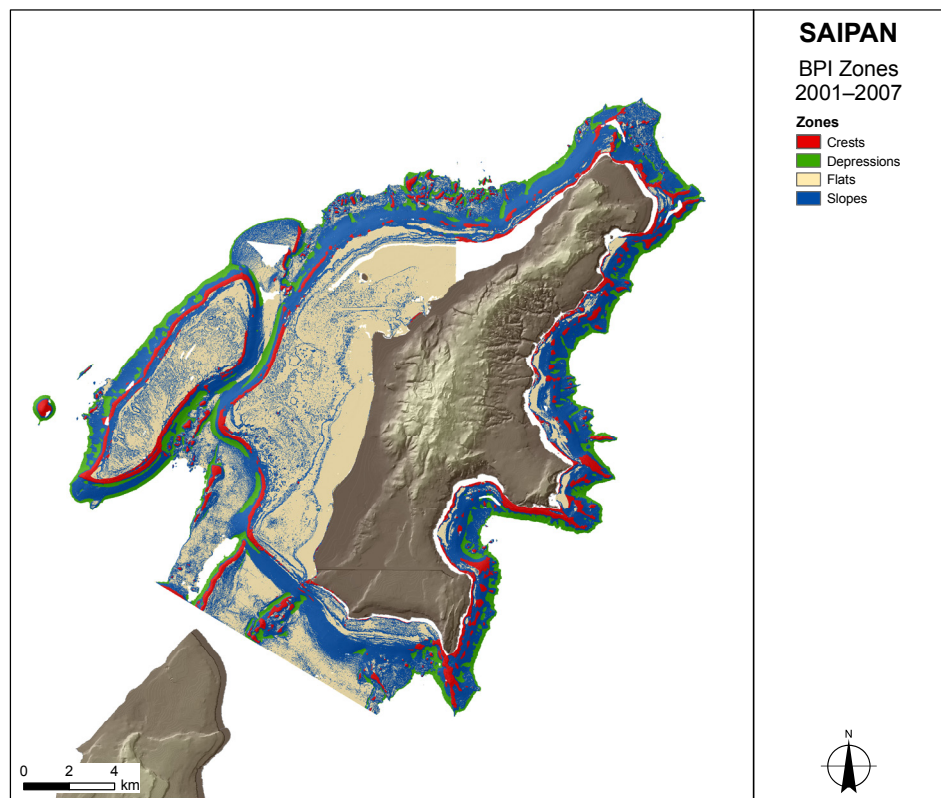
**Figure 8.3.1e.** Rugosity of 5-m bathymetric grid around Saipan. Derived from data collected between 2001 and 2007, these rugosity values are a measure of the ratio of surface area to planimetric area within a given cell's neighborhood and indicate topographic roughness.

Two large, shallow bank areas form significant topographic features west of Saipan. The innermost bank extends offshore for 3–6 km and, with the outer bank, forms Garapan Anchorage. Together, these 2 banks encompass ~ 58 km<sup>2</sup> of seafloor shallower than 50 m. This feature is the largest of its kind in the entire Mariana Archipelago, making it both a unique coral reef habitat and an important anchorage area for large commercial and military vessels. The high-resolution bathymetry, slope, and rugosity data clearly show the topography on these bank tops is characterized by a complex mosaic of mounds and channels, which often supports large areas of coral-rich habitat. Both banks are surrounded by steep slopes that descend into a narrow channel separating them. The base of this channel appears to be very smooth, with low rugosity, although at its southern end, a more rugged topography is shown. West of these banks, a steep pinnacle has a shallow peak at a 100-m depth.

Northwest of Saipan, the most significant topographic features are large blocks of material at the base of the bank slope. Highlighted by the slope, rugosity, and BPI zone maps, this material creates a complex topography that may have been deposited by mass-wasting events.



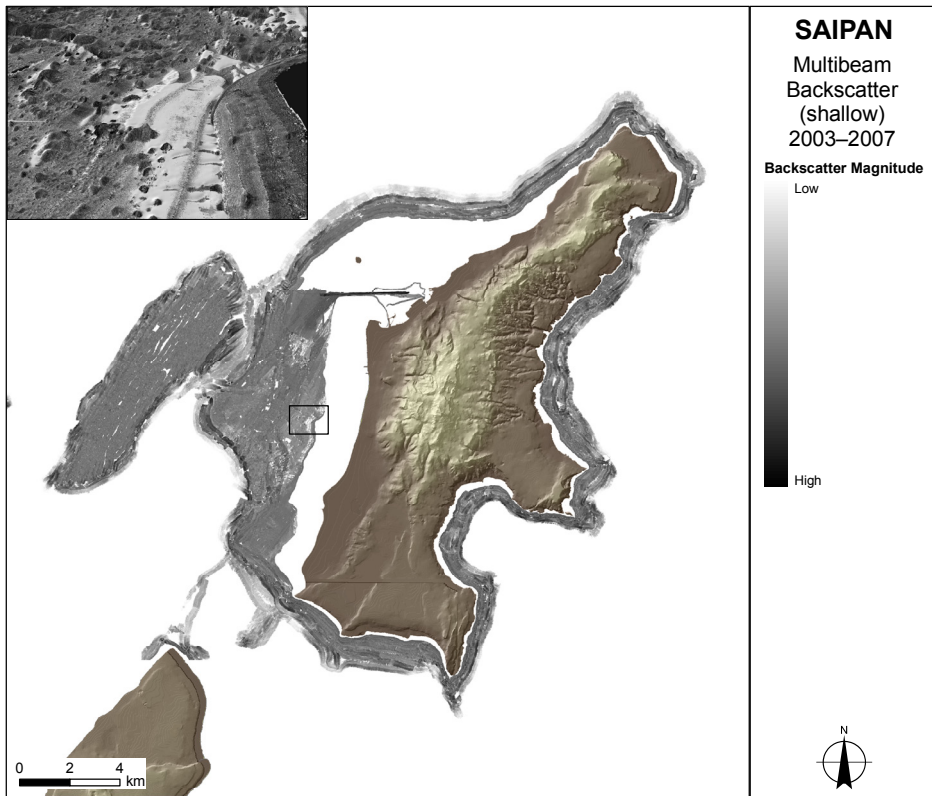
**Figure 8.3.1f.** BPI zones of 5-m bathymetric grid around Saipan derived from data collected between 2001 and 2007. BPI is a second-order derivative of bathymetry that evaluates elevation differences between a focal point and the mean elevation of the surrounding cells within a user-defined circle. Four BPI Zones—crests, depressions, flats, and slopes—were used in this analysis.



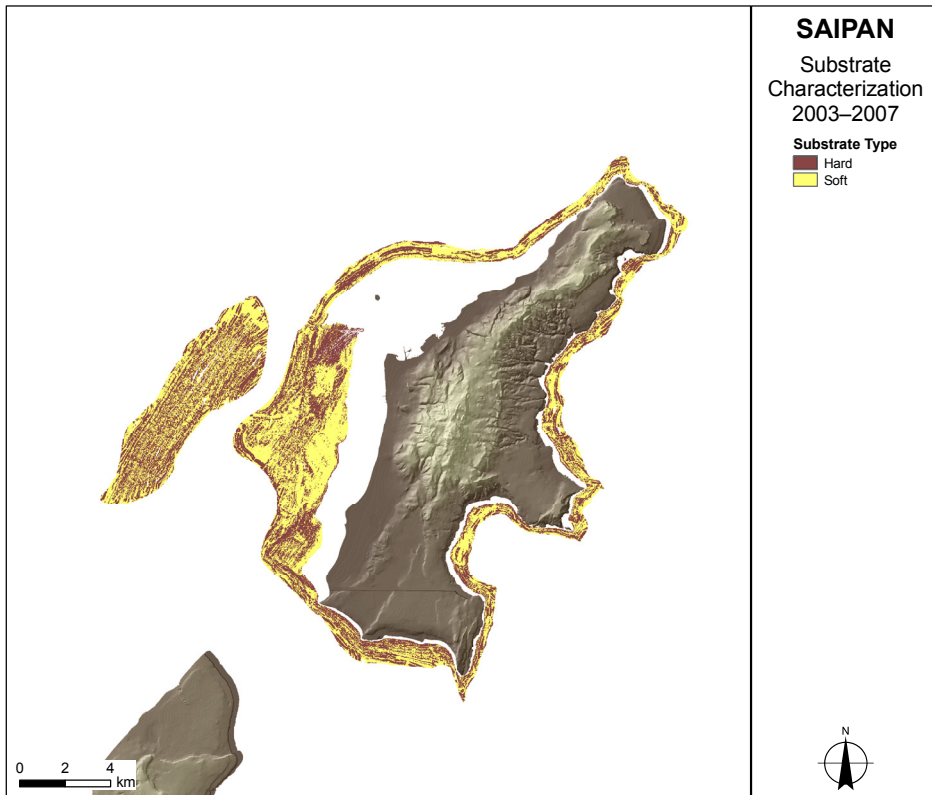
### **High-resolution Multibeam Backscatter and Derivatives**

A number of factors aside from substrate characteristics can affect measured backscatter intensity, including sonar frequency, settings, and slope (see Chapter 2: Methods and Operational Background, Section 2.2.2: “Acoustic Mapping”). In the case of data collected around Saipan, noticeable artifacts are present in the backscatter data that may have resulted from the Reson SeaBat 8101 ER sonar operating at the limit of its capabilities, survey speeds too high for optimum data collection, or steep slopes. Because of these artifacts, unfiltered backscatter data may not accurately reflect the nature of the seabed in these places. To exclude these artifacts from the data, the backscatter data were clipped to a depth of 100 m (Fig. 8.3.1g) prior to deriving the hard–soft substrate map (Fig. 8.3.1h). No backscatter information was available from the lidar data, so only CRED backscatter data are presented in this section.

The backscatter and hard–soft substrate maps show few distinct regional patterns in the distribution of substrate type, but instead show variation at a more local scale. Noticeable areas of hard substrate include a large area in the north part of Garapan Anchorage and a patch of more flat seabed within Bahia Fanonchuluyan, along the shallow shelf south of Saipan. Within Bahia Laolao, southeast of Saipan, the substrate is classified as predominantly soft. This and other areas of soft substrate on the east of Saipan are also characterized with low slopes and rugosity. West of Saipan, the innermost limit of backscatter acquisition was defined by the rim of Lagunan Garapan. Backscatter values in this area show a distinctive pattern with high intensity backscatter recorded along the edge of this lagoon’s forereef slope and low intensity backscatter recorded along a narrow strip immediately adjacent (see the inset in Fig. 8.3.1g). A drape of backscatter intensity over 3-D bathymetry clearly shows that soft sediments collect along the outer edge of this lagoon. This pattern of sediment distribution is likely a result of the accumulation of softer sediments within a low-energy lagoon environment that occasionally overtops the lagoon edge and is deposited immediately outside the lagoon. The outer bank of Garapan Anchorage shows a high level of variation, with small-scale patches, between hard and soft substrates, suggesting numerous channels and mounds on this bank. On the north of this bank, a large patch of soft substrate corresponds to a flat area revealed by the bathymetry and derivative maps.



**Figure 8.3.1g.** Gridded, high-resolution, multibeam backscatter data (grid cell size: 1 m) at depths < 100 m collected around Saipan during MARAMP 2003 and 2007. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom and coral substrates. Inset map shows backscatter draped over 3-D bathymetry in the featured area on the edge of Lagunan Garapan.



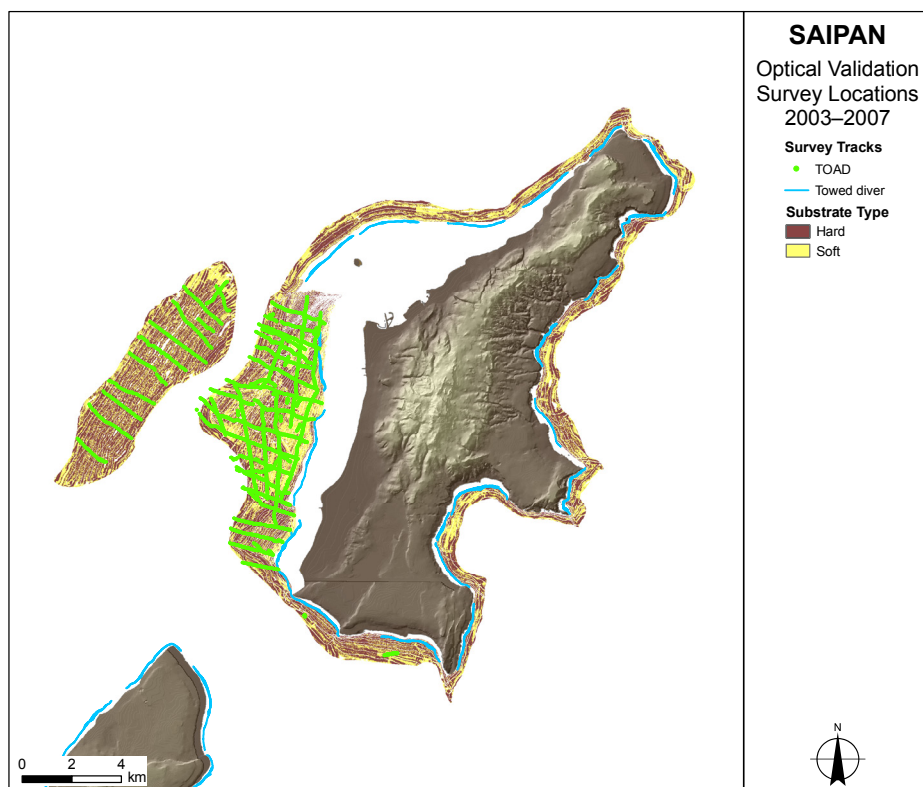
**Figure 8.3.1h.** Hard and soft substrates (grid cell size: 5 m) at depths < 100 m based upon an unsupervised classification of multibeam bathymetry and backscatter data acquired around Saipan between 2003 and 2007.

### 8.3.2 Optical Validation

During MARAMP 2003, 13 TOAD optical-validation surveys of forereef habitats were conducted around Saipan at depths < 140 m (Fig. 8.3.2a). In 2004, through the MSC contract described previously, an additional 41 deployments were completed, covering a distance of 140 km. Subsequent analyses of video acquired from these surveys provided estimates of the percentages of sand cover and live-hard-coral cover.

Covering a distance of 146 km at depths of 5–24 m, 39 towed-diver optical-validation surveys were conducted around Saipan during MARAMP 2003, 2005, and 2007. At 5-min intervals within each survey, divers recorded percentages of sand cover and live-hard-coral cover and habitat complexity using a 6-level categorical scale from low to very high.

**Figure 8.3.2a.** Towed-diver tracks from surveys of forereef habitats conducted around Saipan during MARAMP 2003, 2005, and 2007, and TOAD camera sled tracks for surveys conducted during MARAMP 2003 and in 2004 for the MSC contract. Survey tracks are displayed over the multibeam hard–soft substrate map. Data cannot be collected directly under the ship, hence the white lines showing the ship's path

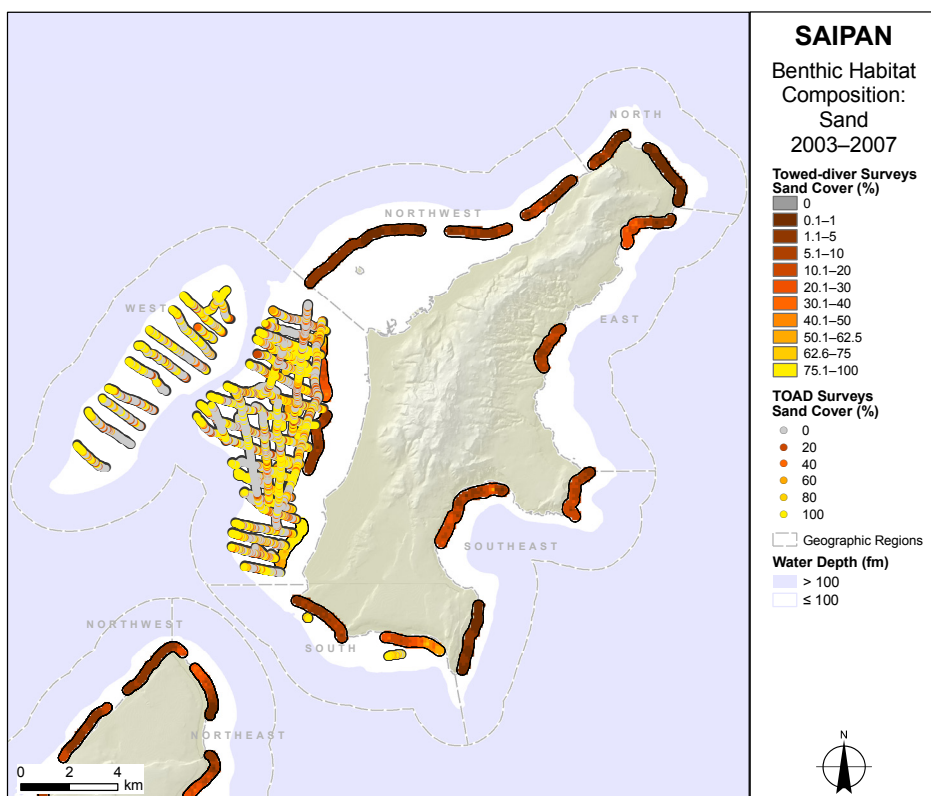


### 8.3.3 Habitat Characterization

Sand cover, habitat complexity, and live coral cover around Saipan are discussed in this section. These descriptions are discussed with reference to the 6 geographic regions around Saipan. Towed-diver observations made around Saipan during MARAMP 2003, 2005, and 2007 revealed a low complexity seabed that was characterized by predominantly hard substrates and low sand cover (Figs. 8.3.3a and b). Live coral cover was generally < 20%, except for a small number of locations described later in this section (Fig 8.3.3c). A large, shallow lagoon, Lagunan Garapan, stretches along the west coast of Saipan, fringed by a barrier reef. Because of its shallow depths it was not possible for towed divers to survey within this lagoon.

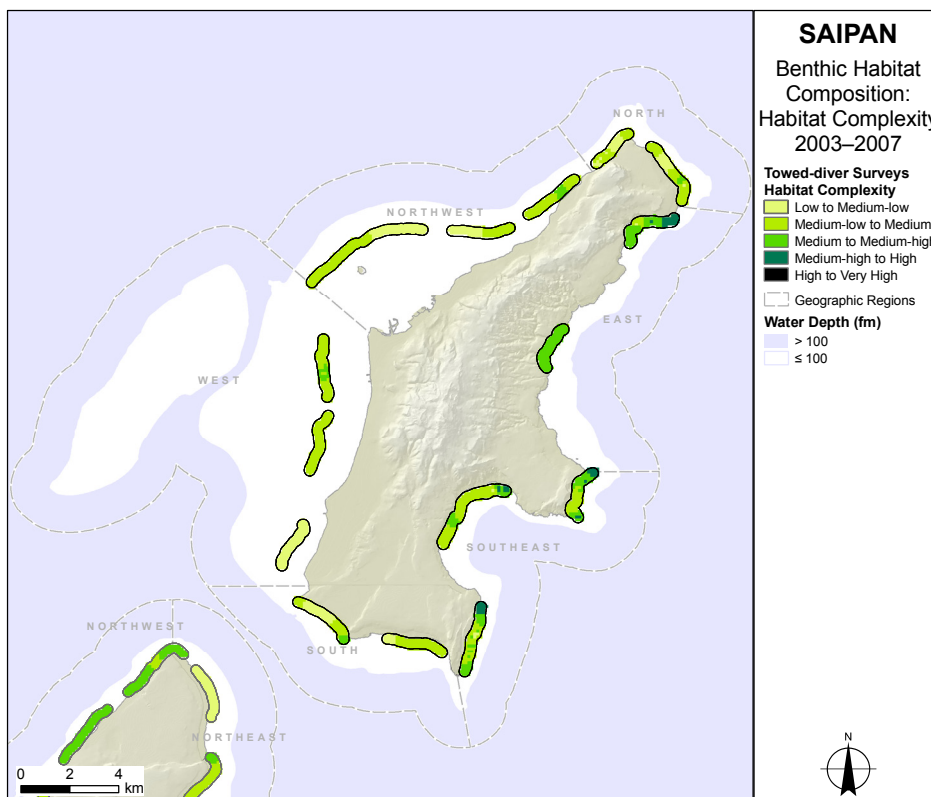
Around north Saipan, the nearshore environment was a predominantly hard substrate, as suggested by the low levels of sand cover recorded during towed-diver surveys. Levels of habitat complexity were observed from low to medium, and live coral cover also was observed as low, except for a small patch of higher cover recorded close to Puntan Sabaneta.

In the southeast region, live coral cover from towed-diver surveys generally ranged from 5.1% to 20%, although higher cover was observed in the north part of Bahia Laolao with interpolated live coral cover of up to 75%. The reef habitat present here was described by towed divers as a moderately sloping reef with sand patches.



**Figure 8.3.3a.** Observations of sand cover (%) from towed-diver surveys of forereef habitats conducted around Saipan during MARAMP 2003, 2005, and 2007 and analysis of TOAD video collected during MARAMP 2003 and in 2004 for the MSC contract.

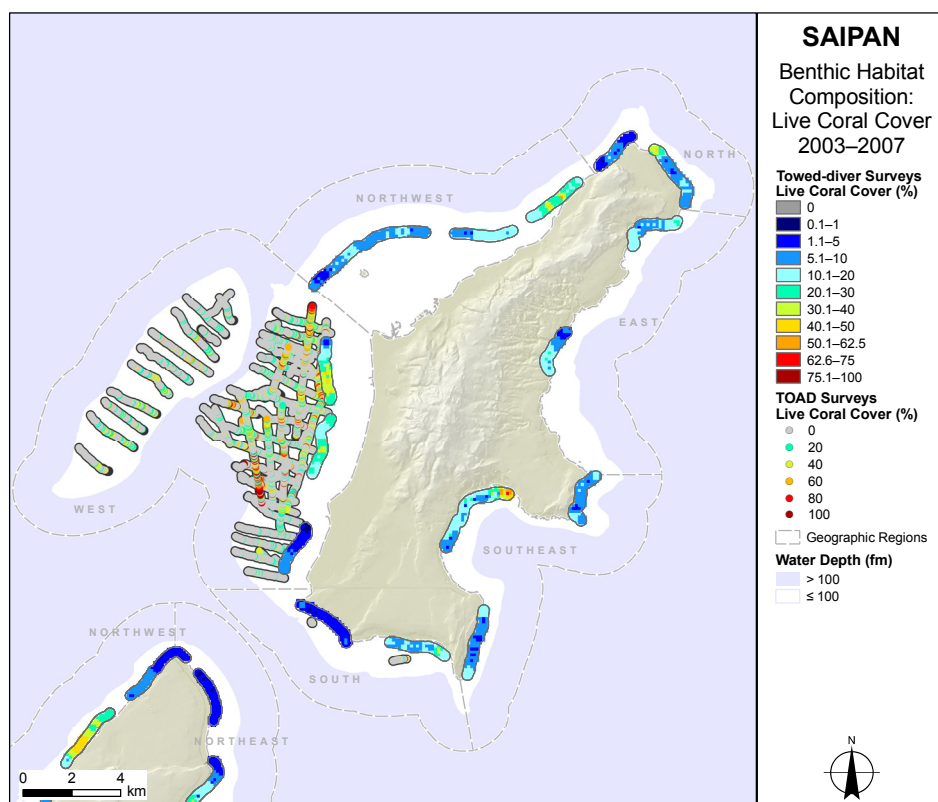
Habitat complexity from towed-diver surveys conducted around Saipan ranged from medium to high. Highly complex habitats were observed in the north part of Bahia Fanonchuluyan in the east region; at Puntan Laolao Kattan, located at the border between the east and southeast regions, corresponding to an area described as containing spur-and-groove reefs and vertical walls; and in the southeast region at Puntan Dandan, where divers observed boulders and crags. Sand cover from towed-diver surveys was generally < 20%, with the highest interpolated sand cover of up to 30% recorded in the middle of Bahia Fanonchuluyan.



**Figure 8.3.3b.** Observations of benthic habitat complexity from towed-diver surveys of forereef habitats conducted around Saipan during MARAMP 2003, 2005, and 2007.

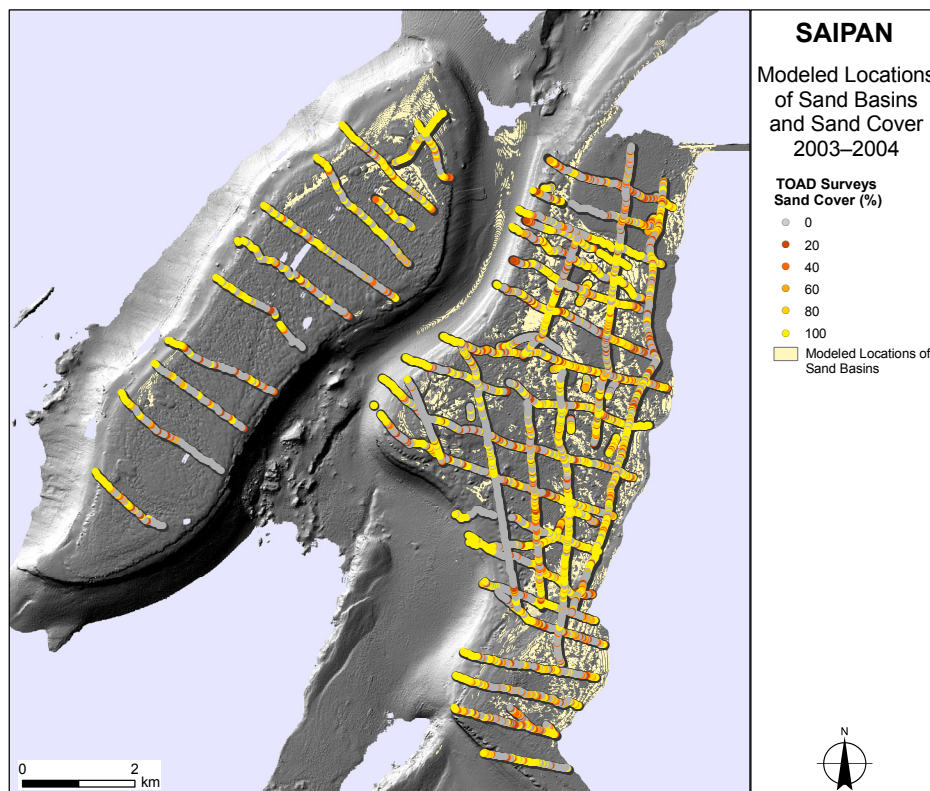


**Figure 8.3.3c.** Cover (%) observations of live hard corals from towed-diver surveys of forereef habitats conducted around Saipan during MARAMP 2003, 2005, and 2007 and analysis of TOAD video collected during MARAMP 2003 and in 2004 for the MSC contract.



Towed-diver surveys recorded low cover of both sand and live corals between Puntans Agingan and Unai Opyan in the south region, suggesting a hard substrate habitat. Habitat complexity was also low. East of Puntan Unai Opyan, however, habitat complexity and sand cover were slightly higher, although still sufficiently low to suggest predominantly hard substrates.

**Figure 8.3.3d.** Observations of sand cover (%) from analysis of TOAD video overlaying estimated locations of sand basins modeled from the 5-m bathymetry grid (shown in light yellow) in the Garapan Anchorage area (Cutter 2004).



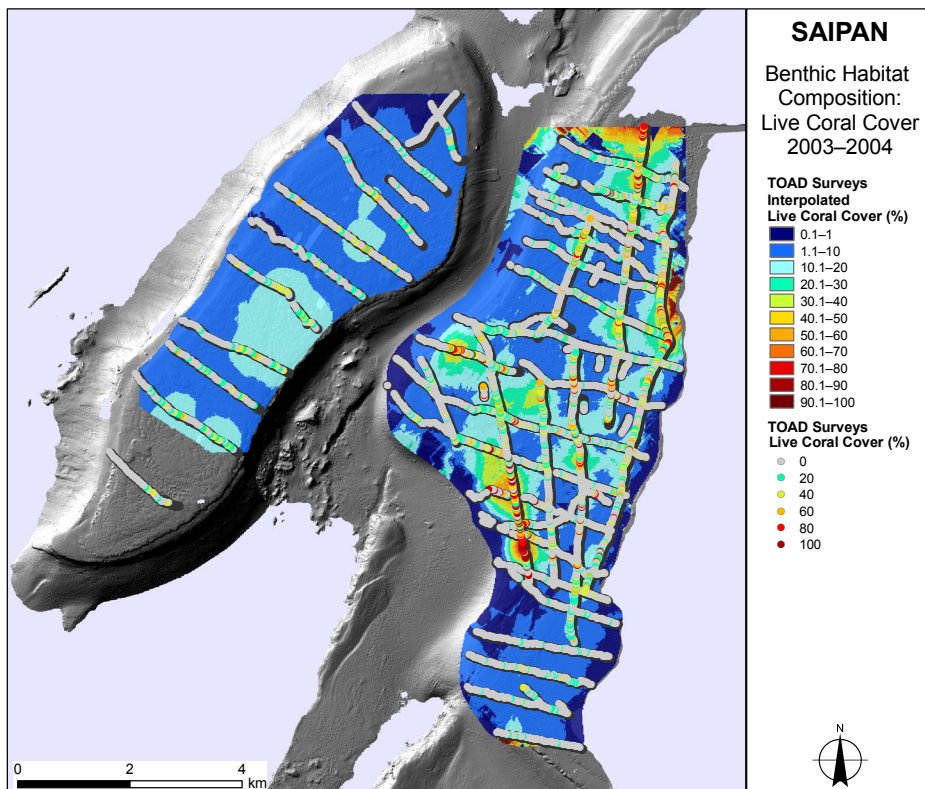


Live coral cover from towed-diver surveys generally ranged from 5.1% to 20%. In deeper waters south of Saipan, analyses of TOAD survey video footage suggest an area of flatter, smoother seabed. Here, analyses of video footage suggest a predominantly sandy seafloor. Live coral cover estimated from TOAD surveys was generally low, although a small number of individual video frames showed high cover, suggesting a patchy distribution of live corals.

In the west region, 2 extensive banks form a large anchorage area, Garapan Anchorage. As described previously at the beginning of this section, additional survey work within this anchorage and further analysis of acoustic data were conducted, allowing for a more complete picture of habitat distribution within this area.

A modeled distribution of sand basins in Garapan Anchorage (Fig. 8.3.3d) shows sand cover is higher on the inner anchorage versus the outer anchorage. The modeled sand basin map, hard-soft map (Fig. 8.3.1h), and analyses of TOAD video footage (Fig. 8.3.3a) together suggest that the outer anchorage is predominantly composed of hard substrate. Sand cover that is higher than in other areas is shown within the flat channels that can be seen on the slope map in between the mound features. Analyses of TOAD video footage also suggest high sand cover along the western edge of the outer anchorage bank top. However, the modeled distribution of sand basins appears to under-represent this long strip of sand, highlighting the importance of ground-truthing modeled products with optical data.

The sand distribution predicted for the inner anchorage area corresponds well to the topographic features revealed by the slope map, with relatively high sand cover in numerous small channels that can be seen on the slope map and low cover on the mounds. Some differences, however, are observed between the map of modeled sand basin distribution and the hard-soft map, which was derived from the unsupervised classification of backscatter data (Fig. 8.3.1g). For example, in the innermost part of the inner anchorage, the hard-soft map shows a large area of soft substrate whereas the modeled sand map predicts a lower sand cover. Analyses of TOAD video footage, meanwhile, suggest high sand cover in this area, although areas of low sand cover were also present, suggesting patchy sand distribution. Similarly, southwest of Puntan Susupi in the west region, the hard-soft map shows an area of predominantly hard substrate and the map of modeled sand basins shows an area of sandy substrate. For this area, TOAD video analyses in this area suggest a mixture of high and low sand cover, although the pattern of sand distribution appears to associate better with the hard-soft map rather than the map of modeled sand basin locations. Some of these differences are likely a result of the thinness of the superficial sediment. Where only a thin layer of sand overlies hard substrates, sand will be seen in video footage but acoustic signals will reflect strongly off the underlying hard substrate and result in high backscatter values.



**Figure 8.3.3e.** Cover (%) observations of live hard corals from analysis of TOAD video overlaying interpolated TOAD values for the percentage of the seafloor covered by corals and other benthic fauna in the Garapan Anchorage area.

Interpolated TOAD video data show a higher concentration of live corals on the inner anchorage area than on the outer anchorage (Fig. 8.3.3e). TOAD video analyses revealed the presence of live corals throughout both anchorage areas, including frequent observations at mesophotic depths ( $> 30$  m). Analyses of TOAD survey video footage suggest that live coral cover was high, with cover of 100% observed in numerous TOAD video images for large areas of mounds, which can be seen on the slope map (Fig. 8.3.1d). Numerous mounds supporting live coral cover on the inner anchorage were found at depths of 30–50 m, suggesting intermediate-depth mesophotic coral ecosystems (MCEs; Locker 2010). Low live coral cover was found on the flat, predominantly sandy channels in between these mounds. Interpolated TOAD data show an area on the southwest edge of the inner anchorage that supports a concentrated area of high coral cover, frequently of 100%. Depths in this area range from  $\sim 50$  to 80 m, and the area extending from the seabed to the top of the bank, appears to have a slightly different character—with smooth areas of moderate slopes rather than the numerous small mounds seen elsewhere on this bank. Analyses of video footage obtained in this area revealed an extensive MCE, formed primarily by the hard coral *Euphyllia paraanacora*.

Within the outer anchorage area, interpolated live coral cover is generally low, although analyses of TOAD videos footage suggest small areas with live coral cover of 40.1%–60% (Fig. 8.3.3e). While the interpolated data provide an indication of areas of relatively high live coral cover, this map oversimplifies the natural spatial heterogeneity in distribution live corals that is revealed by the TOAD video analyses.

Both the TOAD video analyses and interpolated map suggest that, although numerous topographic features can be seen from acoustic data and could indicate the presence of patch reefs, many of these features support few or no live corals. Still, the interpolation of live coral cover in Garapan Anchorage must be treated with some caution. Despite the high number of TOAD deployments conducted, optical data were not available for large areas of Garapan Anchorage. Interpolated products provide a general overview of the patterns of benthic habitat distribution. However, these patterns are less robust in very heterogeneous sites and in areas, such as Garapan Anchorage, where damage from anchor chains has impacted large areas. For these reasons, areas of high coral concentration could have been overlooked if they were not surveyed by TOAD deployments.

## 8.4 Oceanography and Water Quality

### 8.4.1 Hydrographic Data



#### 2003 Spatial Surveys


During MARAMP 2003, 20 shallow-water conductivity, temperature, and depth (CTD) casts were conducted in nearshore waters at the island of Saipan over the period of August 21–22. Data from these casts show relatively well-mixed surface waters with a narrow range in temperature ( $< 0.7^{\circ}\text{C}$ ) and salinity ( $< 0.2$  psu). Spatial comparisons of water properties at a depth of 10 m reveal slightly lower temperatures ( $29.45^{\circ}\text{C}$ – $29.57^{\circ}\text{C}$ ), higher salinities (34.34–34.39 psu), and associated higher densities ( $21.4$ – $21.44$   $\text{kg m}^{-3}$ ) around the northwest corner of Saipan (casts 7–9) relative to other areas around this island, suggesting greater mixing with deep water or localized upwelling (Fig 8.4.1a). Vertical comparisons of CTD profiles confirm that waters were cooler and well mixed to a depth of 30 m in the north region (Fig. 8.4.1b). This interpretation is consistent with observations of vigorous tidal flows around the northern tip of this island. Waters (casts 17–20) were warmer, slightly less saline, and more stratified in the southeast region than in other areas at Saipan, with the highest temperature of  $30.03^{\circ}\text{C}$  and the lowest salinity of 34.25 psu both recorded in Bahia Laolao (for place-names and their locations, see Fig. 8.2a in Section 8.2: “Survey Effort”). The causal mechanism for these water conditions is unknown but may be simply a diurnal effect (i.e., these casts were collected later in the day than were others). Beam transmission values were  $> 91\%$  at most cast locations, except in the vicinity of Saipan Harbor (casts 2–3), where transmission values were as low as 82.42%.

## SAIPAN

10-m CTD Data 2003

Water Depth (fm) 5 Cast Number

 > 100  
 ≤ 100

 Geographic Regions

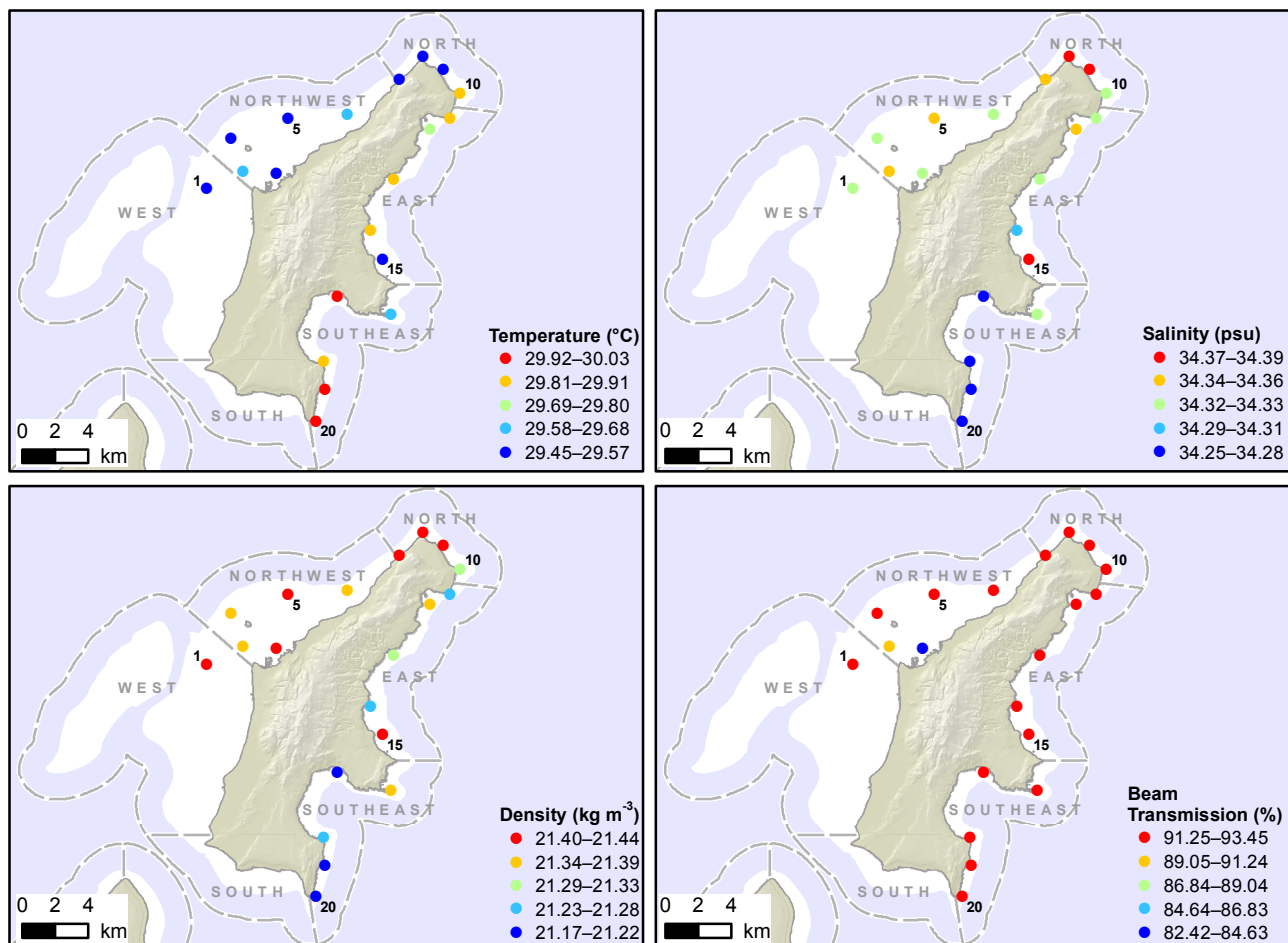
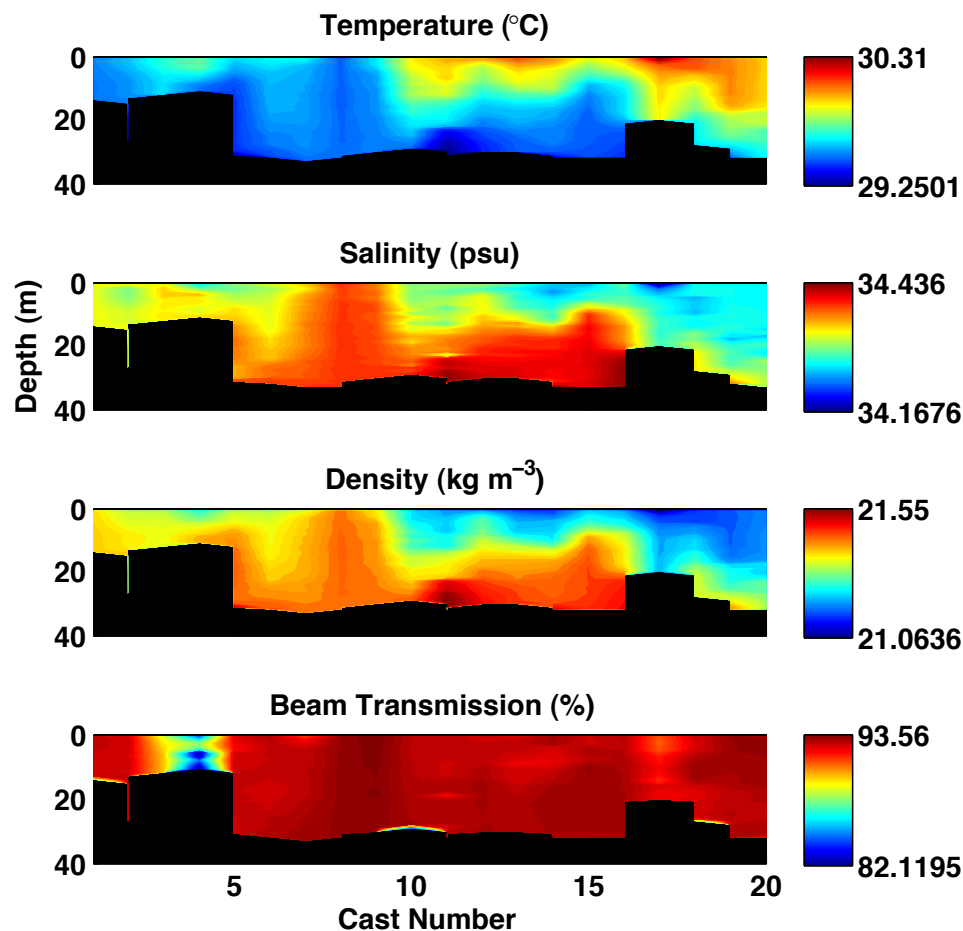


Figure 8.4.1a. Values of (top left) water temperature, (top right) salinity, (bottom left) density, and (bottom right) beam transmission at a 10-m depth from shallow-water CTD casts at Saipan on August 21–22 during MARAMP 2003.

**Figure 8.4.1b.** Shallow-water CTD cast profiles to a 30-m depth at Saipan on August 21–22 during MARAMP 2003, including temperature ( $^{\circ}\text{C}$ ), salinity (psu), density ( $\text{kg m}^{-3}$ ), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–20 in a clockwise direction around Saipan. For cast locations and numbers around this island in 2003, see Figure 8.4.1a.



### 2005 Spatial Surveys

During MARAMP 2005, shallow-water CTD casts were conducted in nearshore waters at Saipan on September 3–4 and September 22. Data from 27 of these casts show a blend of stratified and well-mixed surface waters, depending on location at Saipan. Spatial comparisons of water properties at a depth of 10 m show lower temperatures ( $28.59^{\circ}\text{C}$ ), higher salinities (34.56 psu), and associated higher densities ( $21.88 \text{ kg m}^{-3}$ ) in the north region than in other areas at Saipan (Fig. 8.4.1c), suggesting greater mixing with deep water or localized upwelling. Beam transmission values were lower (91.96%) in the west region (cast 2) near Saipan Harbor than in other regions. Vertical comparisons (Fig. 8.4.1d) of CTD profiles reveal a well-mixed water column in most cast locations; however, at select locations, the water column exhibited greater stratification (casts 2–3, 6–8, 22–23). Broad ranges in temperature ( $\sim 1^{\circ}\text{C}$ ) and beam transmission ( $\sim 4\%$ ) were observed, with the highest temperature ( $29.34^{\circ}\text{C}$ ) and lowest beam transmission (90.05%) values recorded near Saipan Harbor (cast 2). These large ranges could have resulted from temporal separation in sampling.

Water samples were collected in concert with shallow-water CTD casts at select locations at Saipan in 2005 to assess water-quality conditions. The following ranges of measured parameters were recorded: chlorophyll-*a* (Chl-*a*),  $0.12\text{--}1.50 \mu\text{g L}^{-1}$ ; total nitrogen (TN),  $0.07\text{--}0.17 \mu\text{M}$ ; nitrate ( $\text{NO}_3^-$ ),  $0.07\text{--}0.15 \mu\text{M}$ ; nitrite ( $\text{NO}_2^-$ ),  $0.00\text{--}0.03 \mu\text{M}$ ; phosphate ( $\text{PO}_4^{3-}$ ),  $0.00\text{--}0.04 \mu\text{M}$ ; and silicate [ $\text{Si}(\text{OH})_4$ ],  $0.33\text{--}0.77 \mu\text{M}$ . Minimum nitrite values (0.00) were close to immeasurable levels. Based on data from 6 sample locations, water-quality data show that Saipan Harbor contained the highest Chl-*a* and nutrient values (Fig. 8.4.1e).



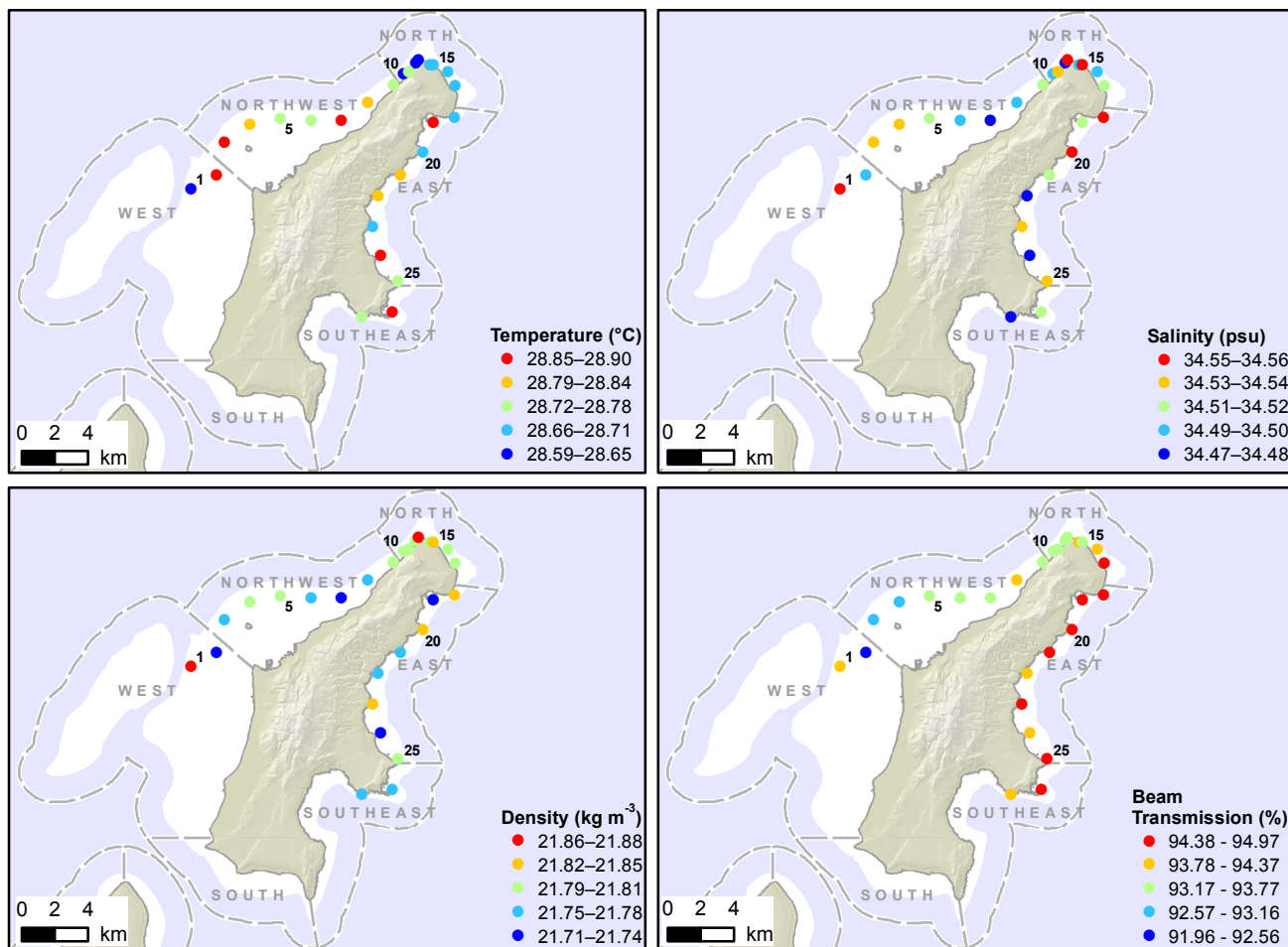
## SAIPAN

10-m CTD Data 2005

Water Depth (fm) 5 Cast Number

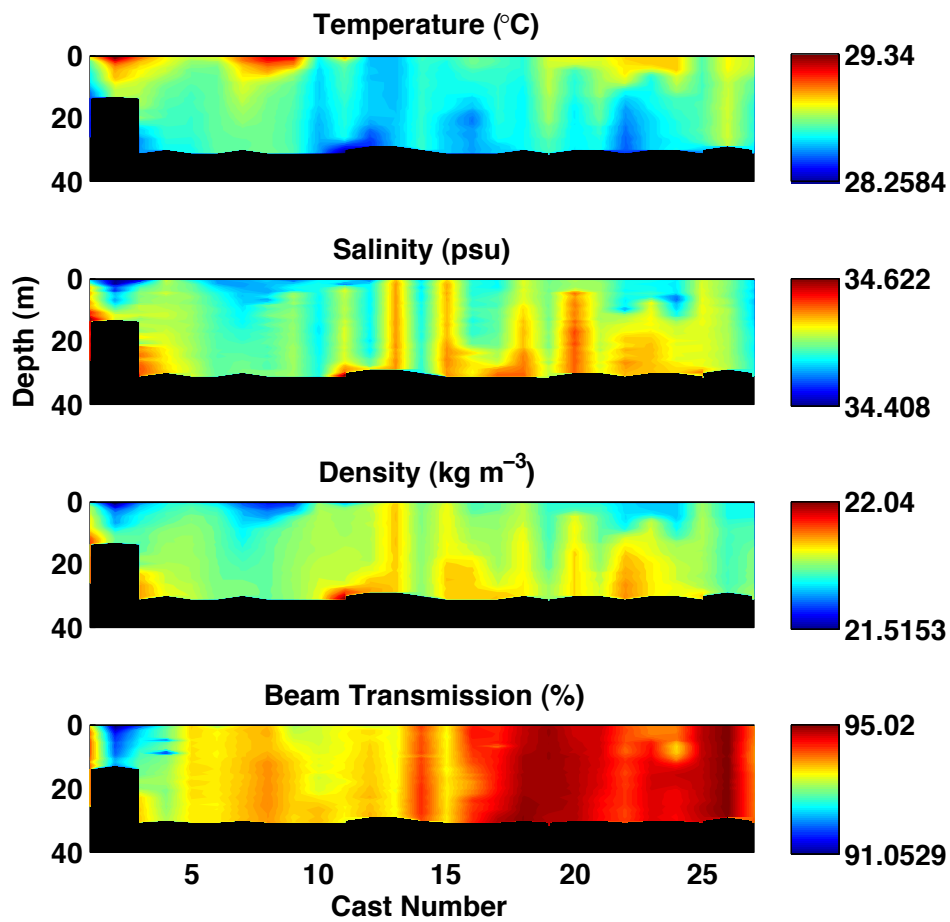
> 100  
≤ 100

Geographic Regions



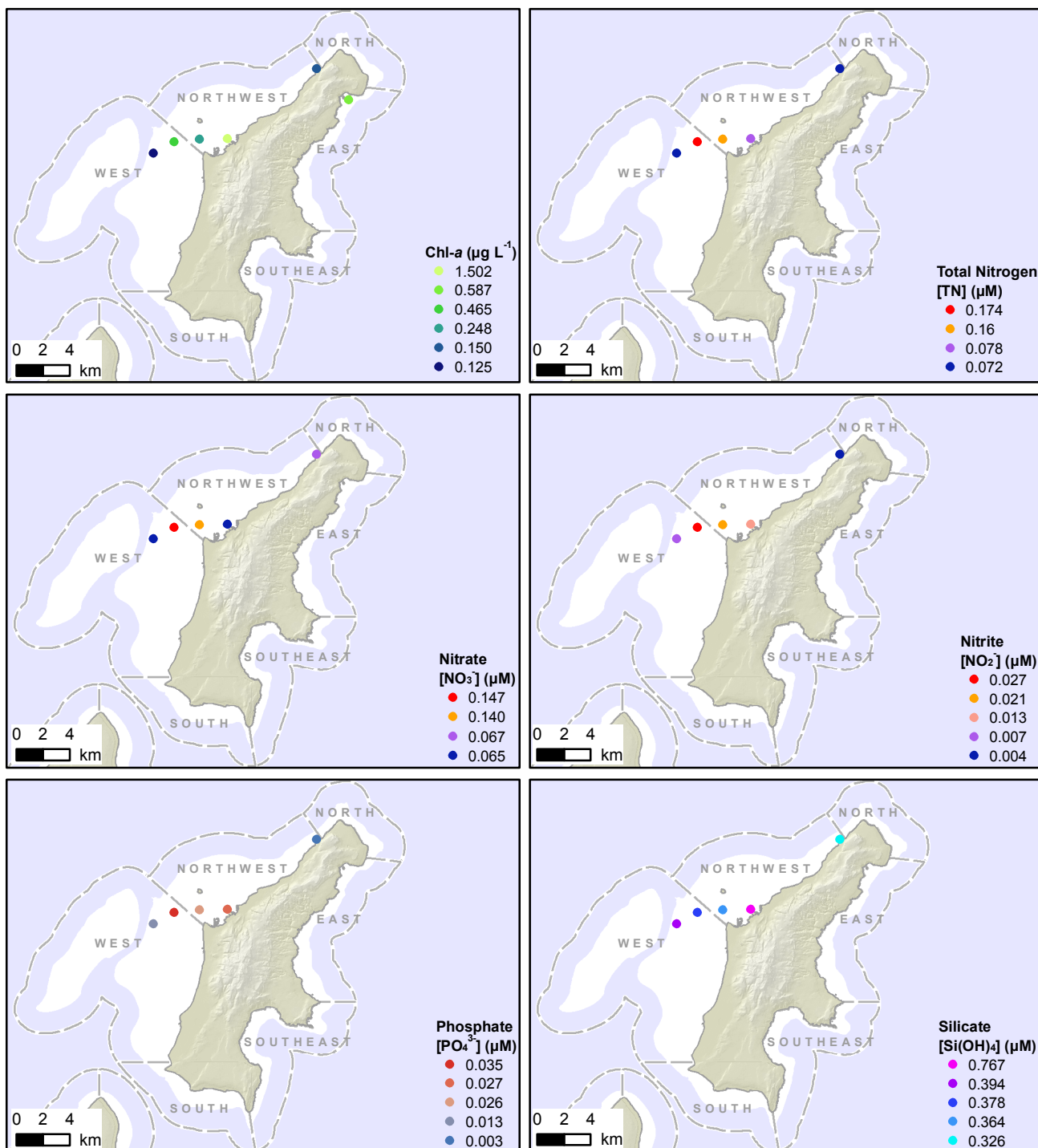
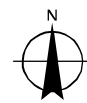
**Figure 8.4.1c.** Values of (top left) water temperature, (top right) salinity, (bottom left) density, and (bottom right) beam transmission at a 10-m depth from shallow-water CTD casts at Saipan during MARAMP 2005, with casts 10, 12, 14, 16, and 17 done on September 3, casts 18–27 done on September 4, and casts 1–9, 11, 13, and 15 done on September 22.

**Figure 8.4.1d.** Shallow-water CTD cast profiles to a 30-m depth at Saipan during MARAMP 2005, including temperature ( $^{\circ}\text{C}$ ), salinity (psu), density ( $\text{kg m}^{-3}$ ), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–27 in a clockwise direction around Saipan. Casts 10, 12, 14, 16, and 17 were completed on September 3, casts 18–27 were done on September 4, and casts 1–9, 11, 13, and 15 were done on September 22. For cast locations and numbers around this island in 2005, see Figure 8.4.1c.



## SAIPAN

10-m Nutrient Data 2005

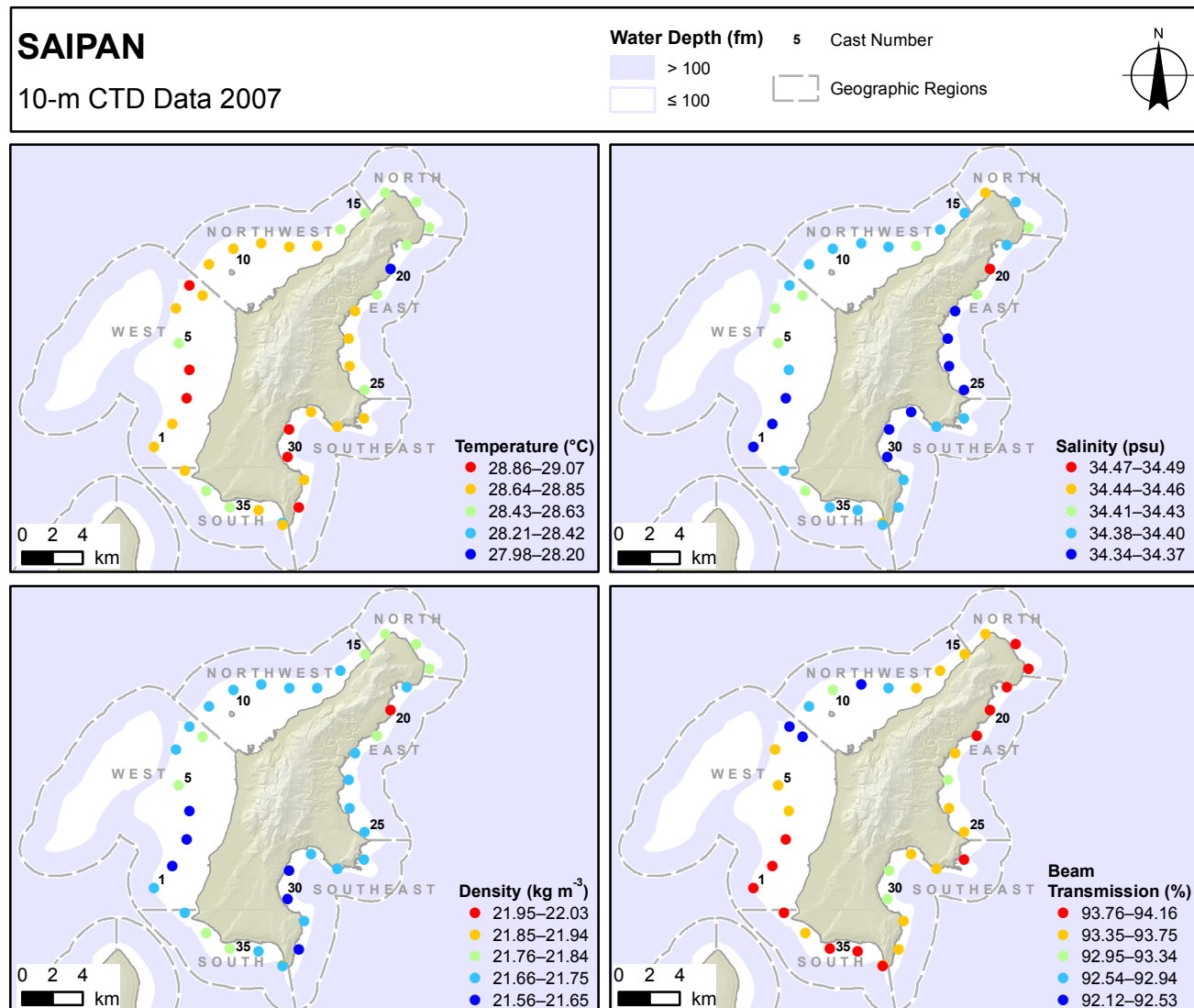
Water Depth (fm)  Geographic Regions> 100  
≤ 100

**Figure 8.4.1e.** Concentrations of (top left) Chl-a, (top right) total nitrogen, (middle left) nitrate, (middle right) nitrite, (bottom left) phosphate, and (bottom right) silicate concentrations at a 10-m depth, from water samples collected at Saipan on September 22 during MARAMP 2005.

## 2007 Spatial Surveys

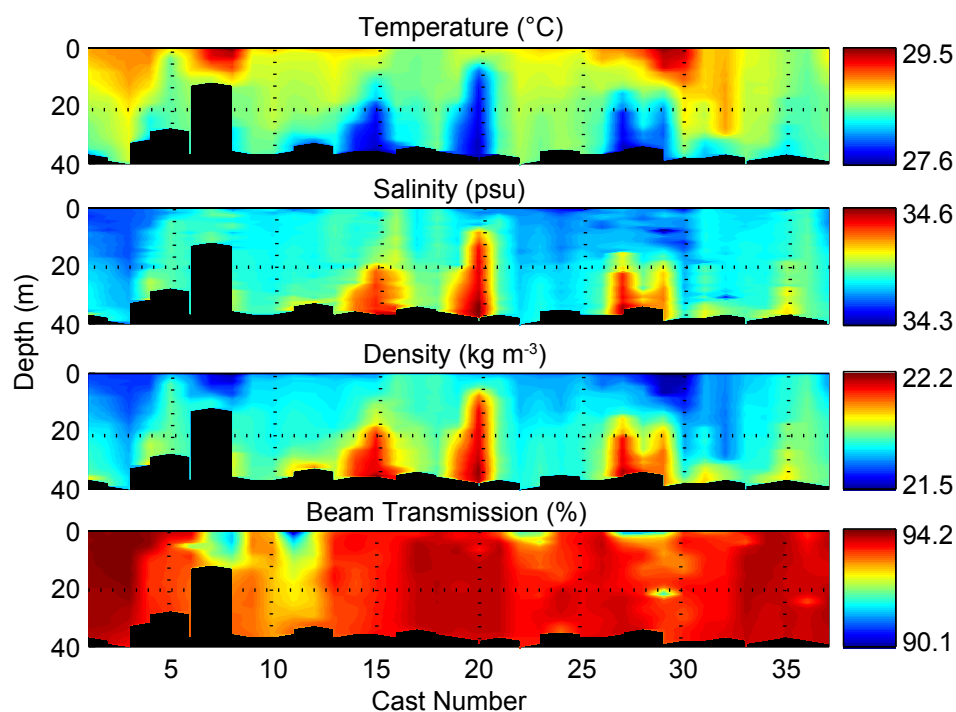
During MARAMP 2007, shallow-water CTD casts were conducted in nearshore waters around Saipan over the period of May 19–21. Temperature, salinity, density, and beam transmission values from 37 of these casts varied both spatially and vertically around Saipan. Spatial comparisons of water properties at a depth of 10 m show moderate ranges in temperature (1.09°C), salinity (0.14 psu), density (0.47 kg m<sup>-3</sup>), and beam transmission (2.04%) values, although these ranges principally result from values from one cast in the east region (cast 20), where colder, more saline, and more dense waters were recorded (Fig. 8.4.1f). Vertical comparisons of CTD profiles reveal substantial ranges in temperature (1.9°C) and salinity (0.3 psu) around Saipan (Fig. 8.4.1g). Areas with the lowest temperatures (27.6°C), highest salinities (34.6 psu), and associated highest densities (22.2 kg m<sup>-3</sup>) for Saipan were observed in the northwest, north, and southeast regions (casts 15, 20, 26–27). These differences in water properties suggest greater mixing with deep water or localized upwelling in these areas, relative to other areas around this island. Beam transmission values varied around this island, with the lowest values recorded in the vicinity of Saipan Harbor and in the northwest regions (casts 7–12).

Water samples were collected in concert with shallow-water CTD casts at 4 select locations at Saipan in 2007 to assess water-quality conditions. The following ranges of measured parameters were recorded: Chl-*a*, 0.04–0.12 µg L<sup>-1</sup>; total nitrogen (TN), 0.03–0.05 µM; nitrate(NO<sub>3</sub><sup>-</sup>), 0.02–0.03 µM; nitrite(NO<sub>2</sub><sup>-</sup>), 0.01–0.02 µM; phosphate (PO<sub>4</sub><sup>3-</sup>), 0.05–0.06 µM; and silicate [Si(OH)<sub>4</sub>], 1.37–2.18 µM. Water-quality data show that Chl-*a* was highest in the northern part of Saipan Harbor in the west region, while most nutrient concentrations were highest in the northwest region near Puntan Makpe' (Fig. 8.4.1h).



**Figure 8.4.1f.** Values of (top left) water temperature, (top right) salinity, (bottom left) density, and (bottom right) beam transmission at a 10-m depth from shallow-water CTD casts around Saipan on May 19–21 during MARAMP 2007.





**Figure 8.4.1g.** Shallow-water CTD cast profiles to a 30-m depth around Saipan on May 19–21 during MARAMP 2007, including temperature (°C), salinity (psu), density (kg m<sup>-3</sup>), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–37 in a clockwise direction around Saipan. For cast locations and numbers around this island in 2007, see Figure 8.4.1f.

# SAIPAN

10-m Nutrient Data 2007

Water Depth (fm)  Geographic Regions

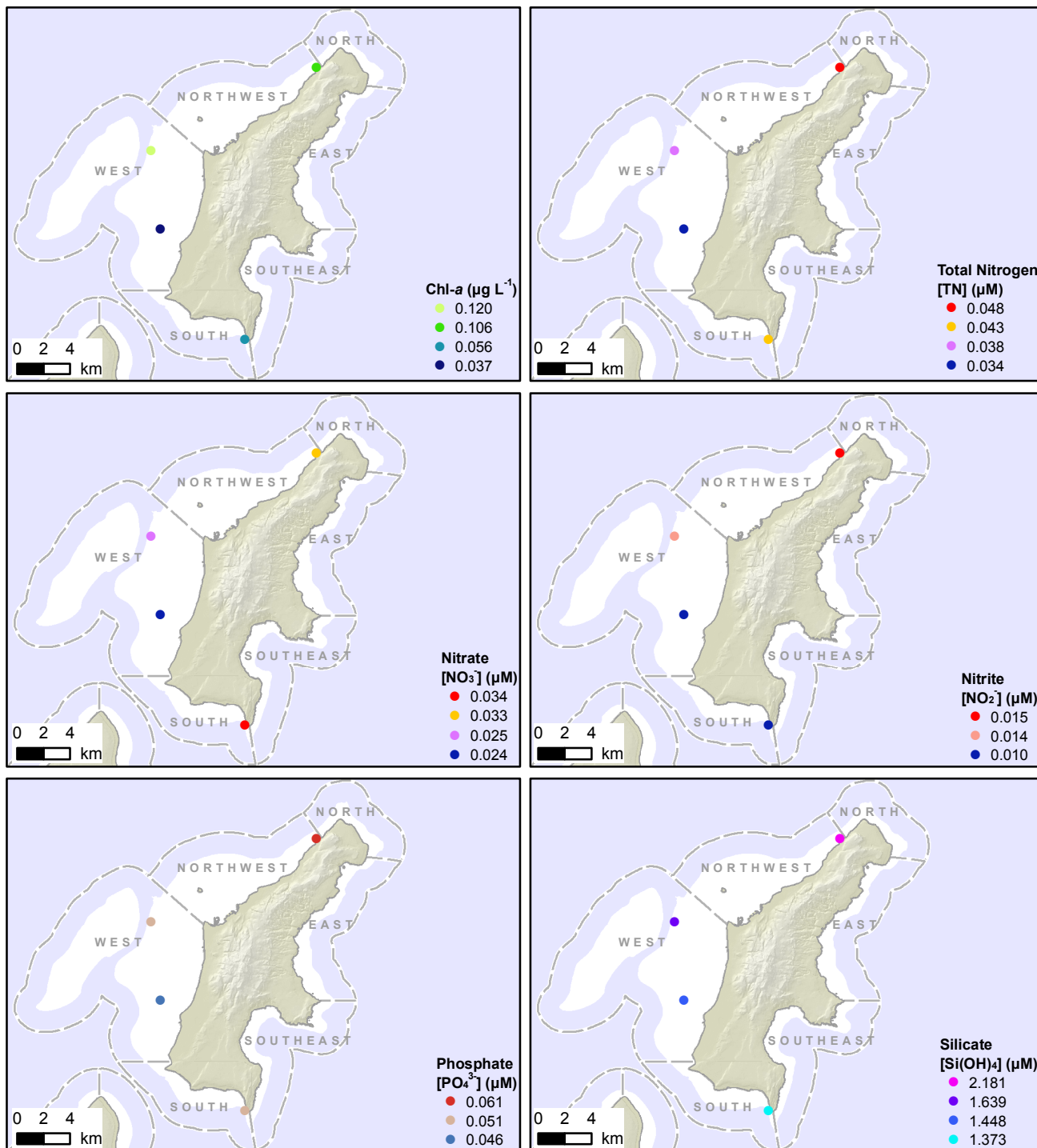
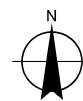


Figure 8.4.1h. Concentrations of (top left) Chl-a, (top right) total nitrogen, (middle left) nitrate, (middle right) nitrite, (bottom left) phosphate, and (bottom right) silicate at a 10-m depth, from water samples collected at Saipan on May 19–21 during MARAMP 2007.

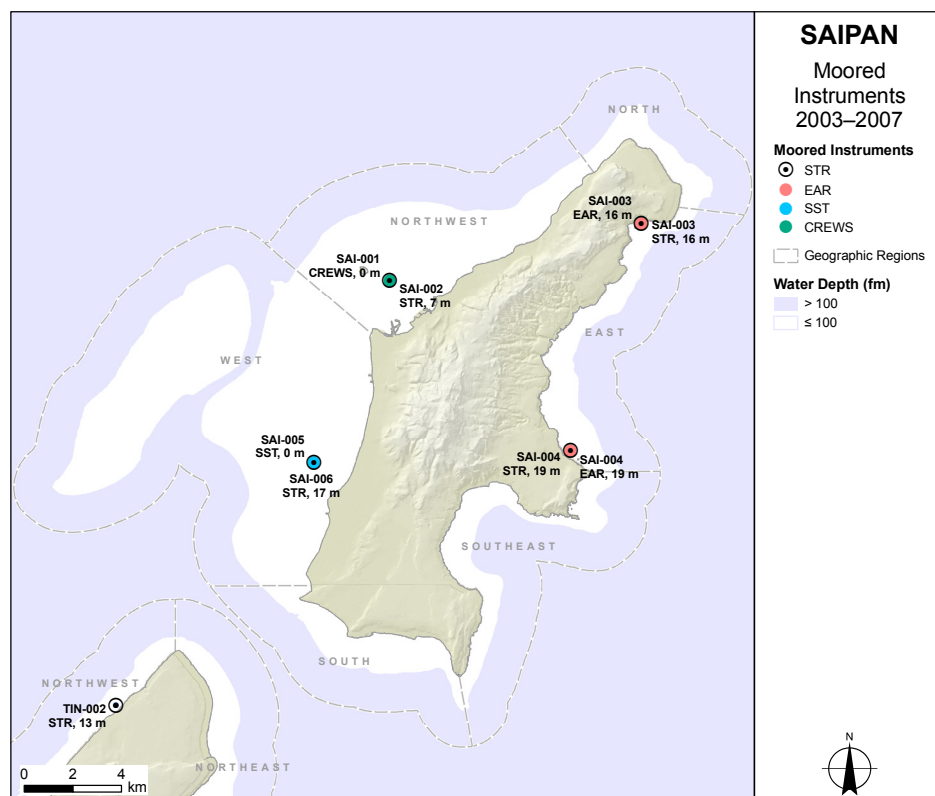
## Temporal Comparison

Data from shallow-water CTD casts performed around Saipan during MARAMP 2003, 2005, and 2007 show temperature ranges  $> 1^{\circ}\text{C}$  within these survey periods, although comparisons between survey years show the maximum temperature was  $\sim 0.9^{\circ}\text{C}$  greater in 2003 than in 2005 and 2007. Vertical gradients in all parameters measured were consistently stronger in the regions sheltered from easterly trade winds than in other areas; however, data from MARAMP 2007 show increased stratification with pronounced, localized, deepwater mixing tongues and less spatial homogeneity than in earlier survey years. In each survey year, mixing with deep water or localized upwelling were evident in the north and east regions. Beam transmission values were  $> 92\%$  at most cast locations; however, beam transmission was generally lowest in the vicinity of Saipan Harbor during each of the survey years. Data were not collected with respect to a specific tidal cycle, which could be a source of oceanographic variability. Likewise, hydrographic variation between MARAMP survey years is likely a result of differences in season. MARAMP 2007 occurred in May, and MARAMP 2003 and 2005 occurred in August and September. This change was made to avoid the typhoon season and reduce the probability of weather disruptions.

Water-quality assessments from water samples collected during MARAMP 2005 and 2007 suggest that Chl-*a*, total nitrogen, nitrate, and nitrite concentrations were much lower in 2007 than in 2005, while phosphate and silicate concentrations were much higher. Whether this variation resulted from a seasonal effect, differences in sample locations between survey years, or some other process is not known at this time. Precipitation data show that MARAMP 2005 occurred during a period of seasonally high precipitation and MARAMP 2007 occurred during a period of seasonally low precipitation (Fig 8.4.2e). The relatively high nutrient and Chl-*a* concentrations observed in 2005 likely are a result of the rise in terrigenous input associated with increases in precipitation. Additionally, strong tidal currents across the Mariana Ridge cause mixing in the southeast and northeast regions around Saipan. This mixing may lead to some nutrient enrichment of surface waters relative to other areas around this island.

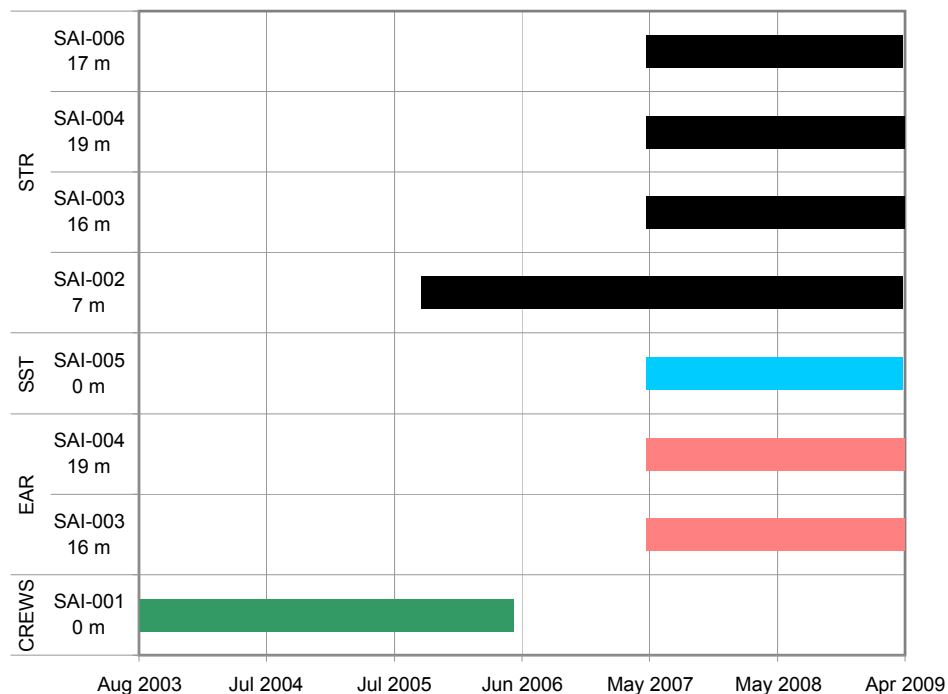
### 8.4.2 Time-series Observations

Between 2003 and 2007, a suite of moored instruments was deployed around Saipan to collect time-series observations of key oceanographic parameters. The locations, depths, time frames, and other details about these deployments are provided in Figures 8.4.2a and b.



**Figure 8.4.2a.** Locations, depths, and types of oceanographic instrument moorings deployed at Saipan during MARAMP 2003, 2005, and 2007. Four types of instruments were moored at Saipan: subsurface temperature recorder (STR), ecological acoustic recorder (EAR), sea-surface temperature (SST) buoy, and Coral Reef Early Warning System (CREWS) buoy.

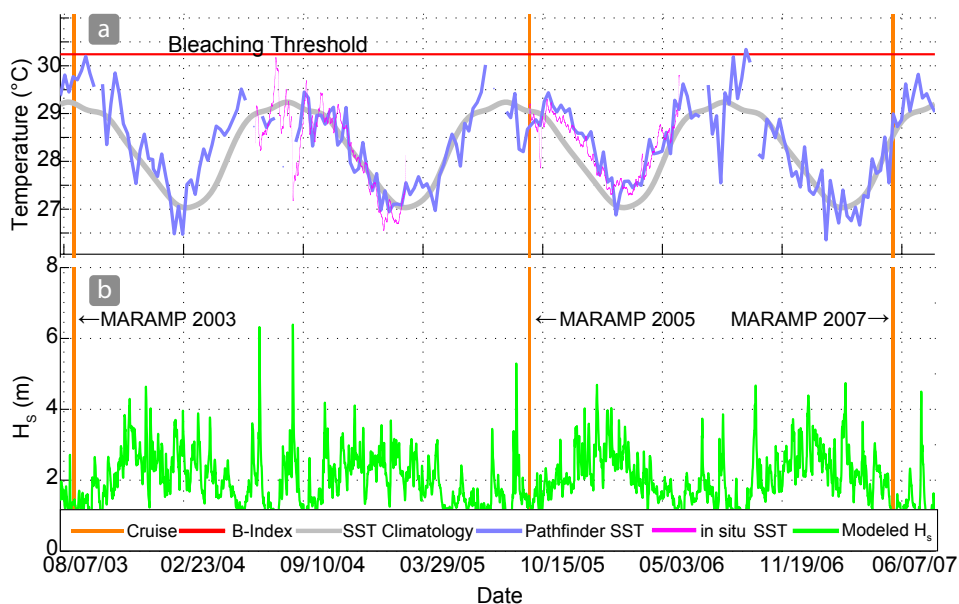
**Figure 8.4.2b.** Deployment timelines and depths of the oceanographic instruments installed around Saipan during the period from August 2003 to April 2009. A solid bar indicates the period for which data were collected by a single instrument or a series of them deployed and retrieved at a mooring site. For more information about deployments and retrievals, see Table 8.2b in Section 8.2: “Survey Effort.” The time period shown in this figure for data stored on and collected from CREWS buoys may differ from the periods for which telemetered SST data, shown in Figure 8.4.2c, was available.



Satellite-derived (Pathfinder) sea-surface temperature (SST) and in situ temperature observations around Saipan reveal that the seasonal maxima for water temperatures around Saipan usually were reached in late August or September; the monthly maximum climatological mean from Pathfinder-derived SST data was 29.5°C (Fig. 8.4.2c[a]). Winter minima occurred in February with a monthly minimum climatological mean of 27.1°C. SST data and subsurface temperature recorder (STR) data show that water temperatures rose above the coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean, around Saipan in August 2003 and September 2006 (Figs. 8.4.2c and d). Still, given the relatively short duration and small magnitude of this period of elevated temperature, widespread mass coral bleaching likely did not occur. It's important to note that satellite-derived SST represents the upper few millimeters of oceanographic temperatures within the region of an island, as opposed to site- or reef-specific temperatures.

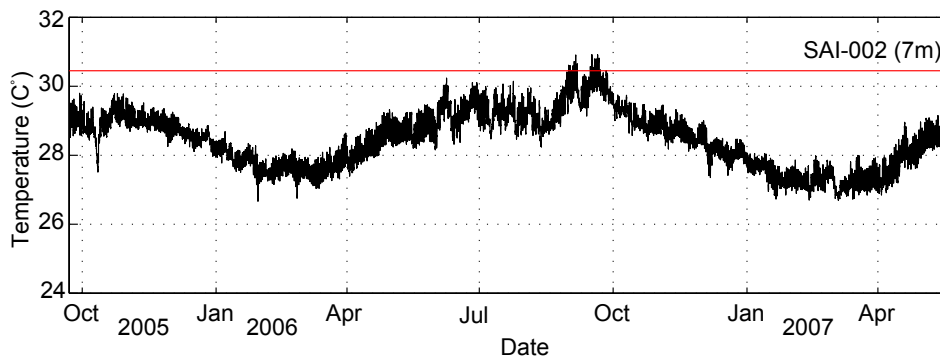
Periods of elevated mean wave heights of 2–4 m were usually more frequent during winter (Fig. 8.4.2c[b]). The largest episodic events of wave heights > 4 m, however, tended to happen during periods of warm temperatures. Warm temperatures typically occur August–December, a period when wave heights > 4 m are generally associated with typhoons. This pattern was especially noticeable during the summer of 2004 with the passages of Typhoons Tinging and Chaba.

**Figure 8.4.2c.** Time-series observations of (a) SST and (b) wave height around Saipan for the period between August 2003 and June 2007. Remotely sensed data (SST climatology and weekly Pathfinder-derived SST) and modeled significant wave height (HS) derived from Wave Watch III are shown with CREW in situ temperature data from CREWS buoys (see Figure 8.4.2a for buoy locations). The 2 high points in the modeled wave height in the summer of 2004 show the occurrences of Typhoons Tinging and Chaba. The horizontal red and vertical orange bars represent the satellite-derived bleaching threshold and the MARAMP research cruise dates, respectively.



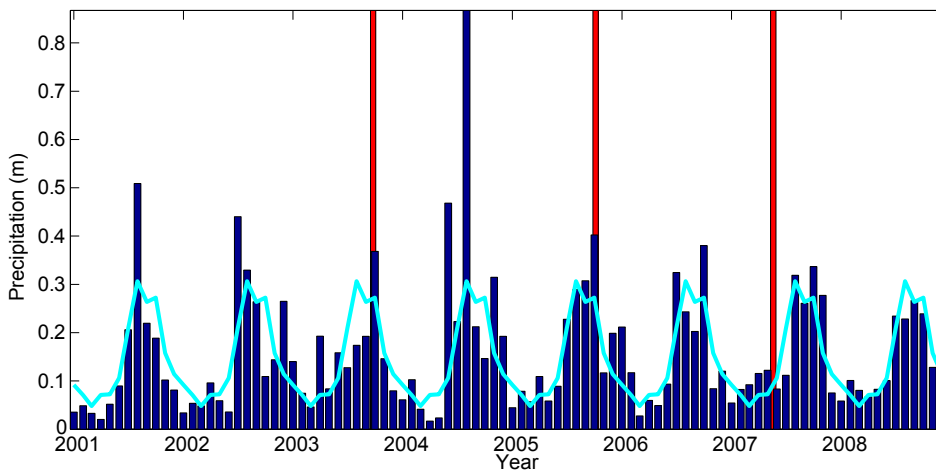


An STR mooring site was established in 2005 at Saipan. Data from the STR deployed at a depth of 7 m at this site in the northwest region near Isleta Managua show a seasonal temperature variability of 3–4°C (Fig. 8.4.2d). Water temperatures reached ~31°C during the months of June–October and fell to a low of ~27°C during the months of January–May. Temperature exceeded the coral bleaching threshold of 30.4°C in September 2006. Diurnal temperature fluctuation was ~1°C throughout this time series.



**Figure 8.4.2d.** Time-series observations of temperature over the period between September 2005 and June 2007 collected from 1 STR mooring site in the northwest region of Saipan at a 7-m depth (see Figure 8.4.2a for the mooring location). The red line indicates the satellite-derived coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean.

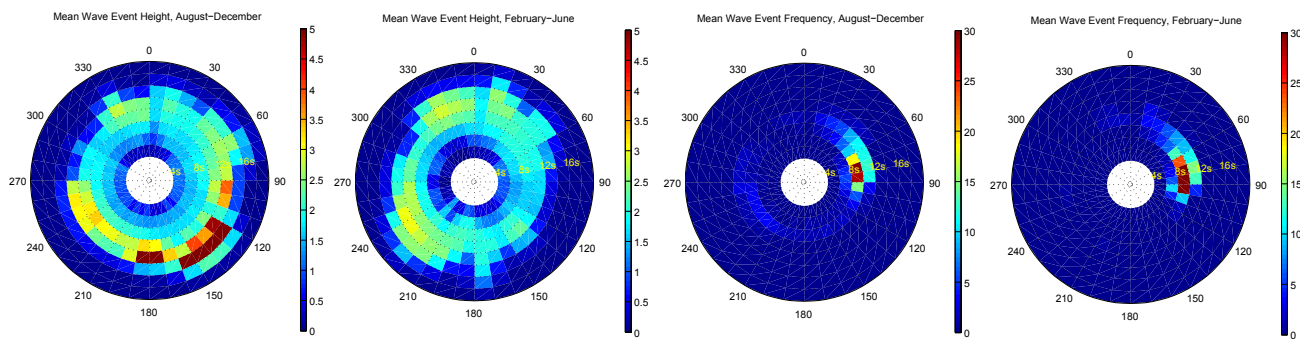
Precipitation at Saipan from 2001 to the end of 2008 was highly seasonal with the greatest rainfall occurring in the months of July–September and the lowest occurring in the months of February–April (Fig. 8.4.2e). MARAMP 2003 and 2005 cruises were conducted in August and September, which are months characterized by seasonally high precipitation. In contrast, MARAMP 2007 was conducted in May when rainfall was seasonally low.



**Figure 8.4.2e.** Average monthly rainfall (m) from the Saipan Airport from January 2001 to July 2008. The cyan line indicates precipitation climatology (1988–2008) and vertical red bars indicate MARAMP cruise periods. Source: National Weather Service, Honolulu, Hawaii (<http://www.prh.noaa.gov/hnl/>).

### 8.4.3 Wave Watch III Climatology

Seasonal wave climatology for Saipan (Fig. 8.4.3a) was derived using the NOAA Wave Watch III model for the period of January 1997 to May 2008, and seasons were selected to elucidate waves generated by typhoons, which most frequently occur during the period of August–December (for information about the Wave Watch III model, see Chapter 2: “Methods and Operational Background,” Section 2.3.7: “Satellite Remote Sensing and Ocean Modeling”). In terms of consistency, the wave regime during this period was dominated by trade wind swells characterized by frequent (> 30 d per season), short-period (8–10 s), relatively small (2–3 m) wave events originating from the east (~75°). Superimposed with these short-period swells were large (> 4 m), long-period (12–16 s) wave events principally from the southeast (135°), although they could originate from a broad directional source (90°–200°). These large, episodic waves primarily were generated by typhoons and occurred on annual to interannual time scales. Additionally, infrequent (~5 d per season), long-period (12–14 s) swells with moderate wave heights (2.5–3.5 m) occurred from the southwest (~240°) and were likely associated with episodic storms. Similar to the regime during typhoon season, the wave regime during the period of February–June (outside the typhoon season) was also characterized by frequent (> 30 d per season), short-period (~8 s) trade wind swells with relatively small wave heights (~2 m) originating from the east. Infrequent (< 5 d per season), long-period (12–14 s) swells with slightly larger wave heights (~3 m) also occurred during this time and originated from the southwest (~240°).

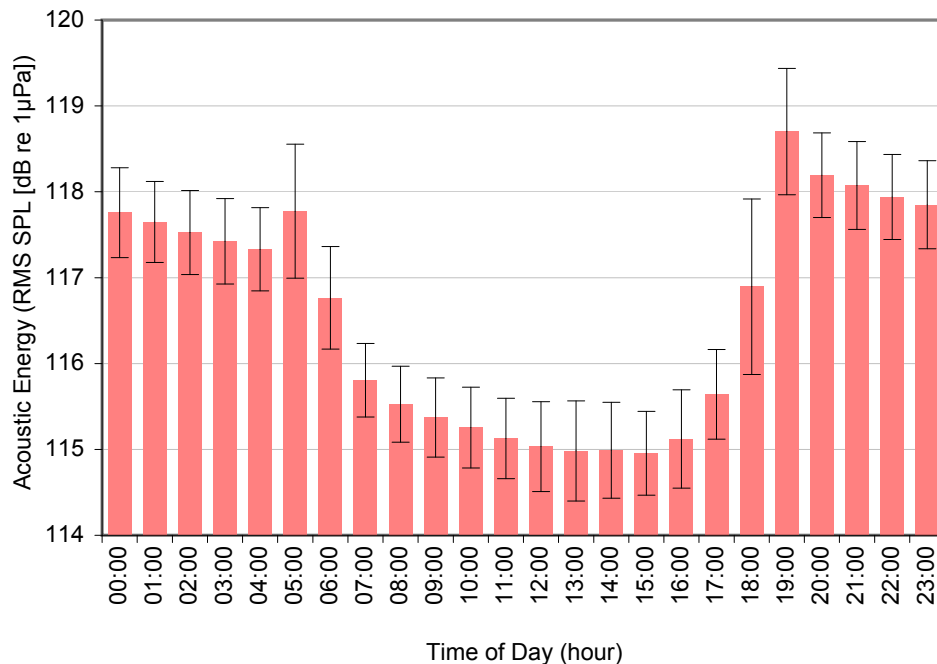


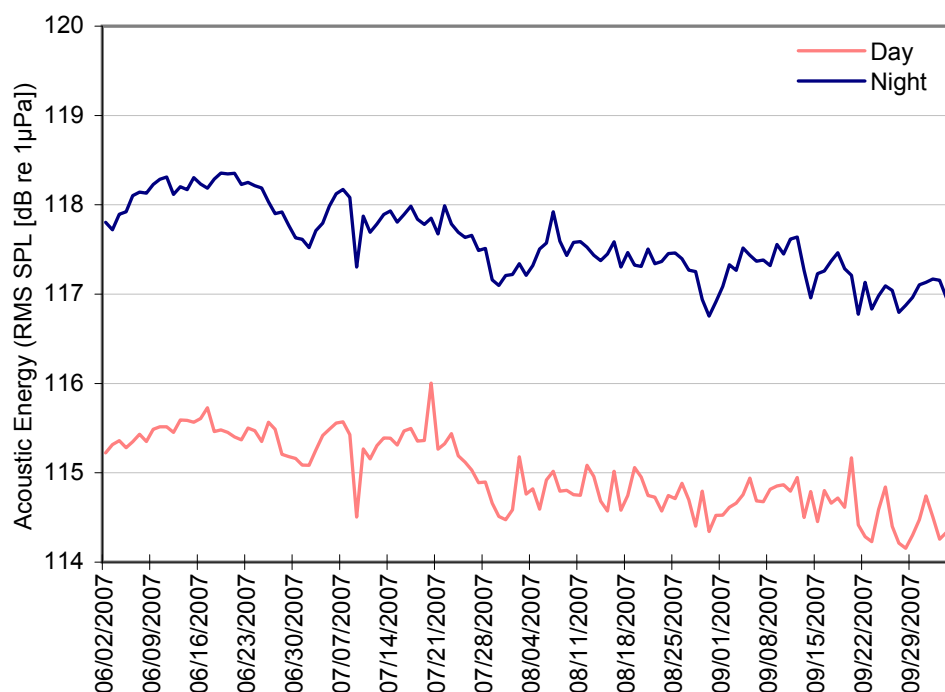
**Figure 8.4.3a.** NOAA Wave Watch III directional wave climatology for Saipan from January 1997 to May 2008. This climatology was created by binning (6 times daily) significant wave height, dominant period, and dominant direction from a box ( $1^\circ \times 1^\circ$ ) centered on Saipan ( $15^\circ$  N,  $145^\circ 45'$  E). Mean significant wave height (*far left and left*), indicated by color scale, for all observations in each directional and frequency bin from August to December (typhoon season) and from February to June. The transition months of January and July are omitted for clarity. Mean number of days (*right and far right*) that conditions in each directional and frequency bin occurred in each season, indicated by color scale; for example, if the color indicates 30, then, on average, the condition occurred during 30 out of 150 days of that season.

#### 8.4.4 Bioacoustic Observations

One ecological acoustic recorder (EAR) unit, co-located with REA site SAI-02 in the east region near Puntan Halaihai, provided a dataset from June 1, 2007 to October 4, 2007. A preliminary analysis of this acoustic energy record—as obtained from the periodic, duty-cycle recordings made by this EAR—revealed strong diel variability. Root mean square sound pressure levels were 3–5 dB higher during the night (12–4 a.m.) than during the day (12–4 p.m., Figs. 8.4.4a and b). This variability probably resulted from fluctuations in the acoustic activity of snapping shrimp. In addition, periodic variability is evident on the scale of several weeks. A second EAR unit, co-located with REA site SAI-01 in Bahia Fanonchuluyan in the east region, has not yet been recovered, and, thus, data from this unit has not been retrieved or analyzed and will not be presented in this report.

**Figure 8.4.4a.** Average hourly acoustic energy, expressed as root mean square (RMS) sound pressure levels (SPL) in decibels (dB) referenced to 1 microPascal ( $\mu$ Pa), from an EAR deployed on the east side of Saipan at the passive acoustics monitoring site near Puntan Halaihai from June 2007 to October 2007.





**Figure 8.4.4b.** Sound pressure levels, averaged over daytime (12–4 p.m.) and nighttime (12–4 a.m.) hours and expressed in root mean square decibels (dB) referenced to 1 microPascal ( $\mu\text{Pa}$ ), at the passive acoustics monitoring site near Puntan Halaihai in the east region of Saipan from June 2007 to October 2007.

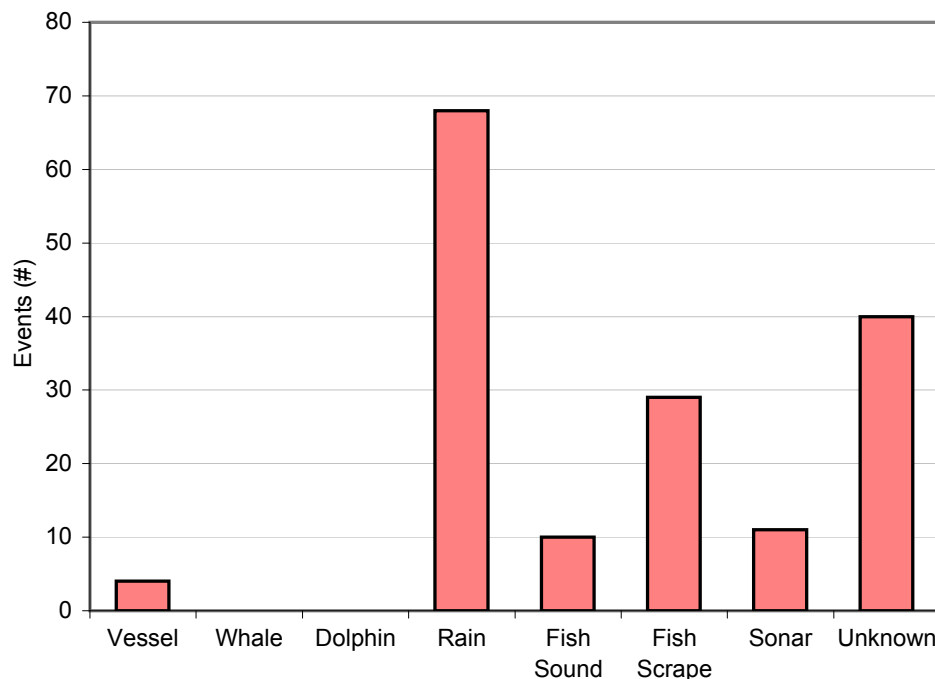
During the 4 months in 2007 for which data were recorded by the EAR near Puntan Halaihai, 4 motorized vessel events had an amplitude and duration sufficient enough to trigger the EAR event detector. Vessel activity was recorded in the vicinity of the EAR unit with 2 events on separate days in July and 2 events during the same day in September (Table 8.4.4a). These initial results suggest this location does not typically encounter much vessel activity. Still, continuous monitoring of this site will provide a more comprehensive assessment and may elucidate seasonal patterns of vessel activity that are not evident in this 4-month record.

A variety of acoustic sources produced recordings on the EAR unit: rain, fish sounds, sonar, and motorized vessels, among others. Analysis of all the event-triggered recordings retrieved from the EAR unit near Puntan Halaihai reveals that the dominant sound was rain, which accounted for 68 recorded events in 2007 (Fig. 8.4.4c). Another sound event was a high-pitched metallic whistle that occurred every 2–3 min over a span of 35 min. Initially labeled as an “unknown anthropogenic source,” this sound was later associated with its most likely source: military sonar.

**Table 8.4.4a.** Summary of vessel sounds that were of sufficient amplitude and duration to trigger the event detector of the EAR deployed near Puntan Halaihai in the east region of Saipan from June 2007 to October 2007.

Vessel Events			
Coordinated Universal Time (UTC)		Chamorro Standard Time (ChST)	
Date	Time	Date	Time
7/19/2007	2:31	7/19/2007	12:31
7/23/2007	20:58	7/24/2007	6:58
9/1/2007	2:29	9/1/2007	12:29
9/1/2007	2:41	9/1/2007	12:41

**Figure 8.4.4c.** Classification of events detected from June 2007 to October 2007 by the EAR deployed at the passive acoustics monitoring site near Puntan Halaihai in the east region of Saipan.



## 8.5 Corals and Coral Disease

### 8.5.1 Coral Surveys

#### *Coral Cover and Colony Density*

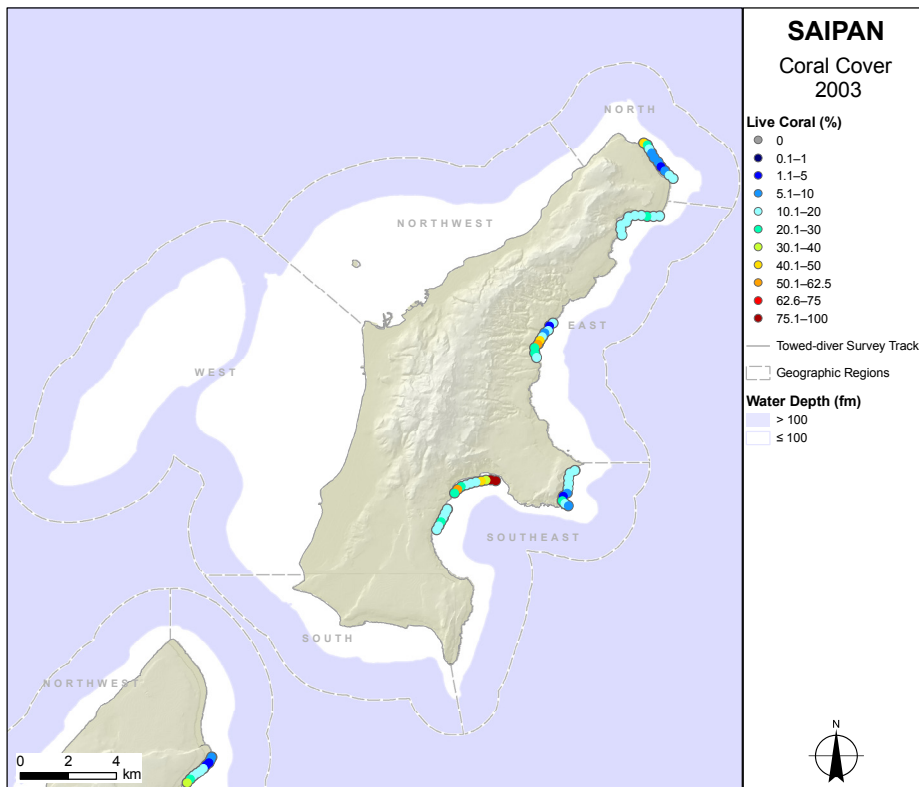
From MARAMP 2003 towed-diver surveys, mean cover of live hard corals on forereef habitats at the island of Saipan was 21% (SE 2.3). Spatial coverage was limited, but, in the areas surveyed, coral cover was highest north of Tuturam in the southeast region with a mean of 64% over 4 survey segments (Fig. 8.5.1a; for place-names and their locations, see Figure 8.2a in Section 8.2: “Survey Effort”). Coral cover at Saipan was lowest along several segments in the north region.

During MARAMP 2003, the 3 REA benthic surveys using the quadrat method on forereef habitats at Saipan documented 325 coral colonies within a total survey area of 11.25 m<sup>2</sup>. Site-specific colony density ranged from 29.6 to 33.1 colonies m<sup>-2</sup> with an overall sample mean of 28.9 colonies m<sup>-2</sup> (SE 2.6). The highest colony density was recorded at SAI-03 in the south-east region, and the lowest colony density was observed at SAI-02 in the east region near Puntan Halaihai (Fig. 8.5.1b).

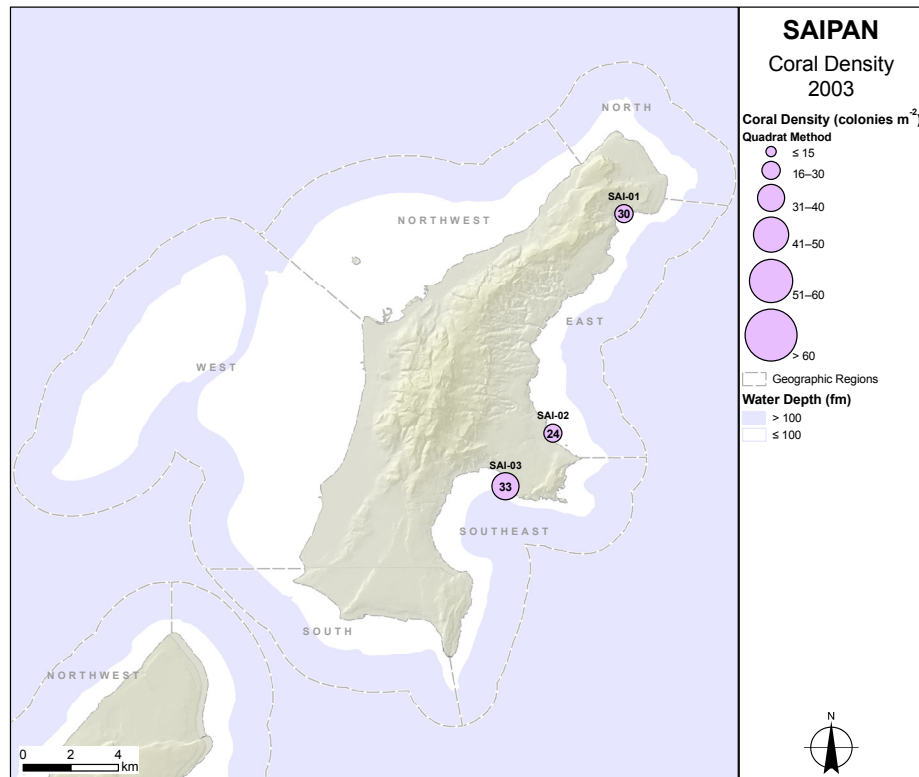
From MARAMP 2005 towed-diver surveys, mean cover of live hard corals on forereef habitats around Saipan was 11% (SE 1). Coral cover was highest in the northwest and west regions with localized high values observed in the northern part of Lagunan Garapan with a mean of 39% for 10 segments and south of Puntan Makpe’ with a mean of 34% for 10 segments (Fig. 8.5.1c). Coral cover was low on forereef habitats in all other regions around Saipan, compared with results from surveys conducted around other islands in the Mariana Archipelago.

Towed divers during MARAMP 2005 recorded estimates of stressed-coral cover, including corals that were fully bleached (white), pale or discolored, malformed, or stricken with tumors (see Chapter 2: “Methods and Operational Background,” Section 2.4.5, “Corals and Coral Disease”). Overall, 2% (SE 0.4) of coral cover observed on forereef habitats around Saipan appeared stressed in 2005. Stressed-coral cover was highest during a survey in the south region between Puntans Opyan and Agingan (Fig. 8.5.1c) with a mean of 17% over 6 nonconsecutive segments. During this same survey, the greatest mean density of crown-of-thorns seastars (*Acanthaster planci*) observed around Saipan during MARAMP 2005 was recorded. Predation by crown-of-thorns seastars (COTS) is one cause of stress and discoloration in corals, and COTS were found at densities high enough to suggest a potential outbreak in this area (see Section 8.7: “Benthic Macroinvertebrates”).



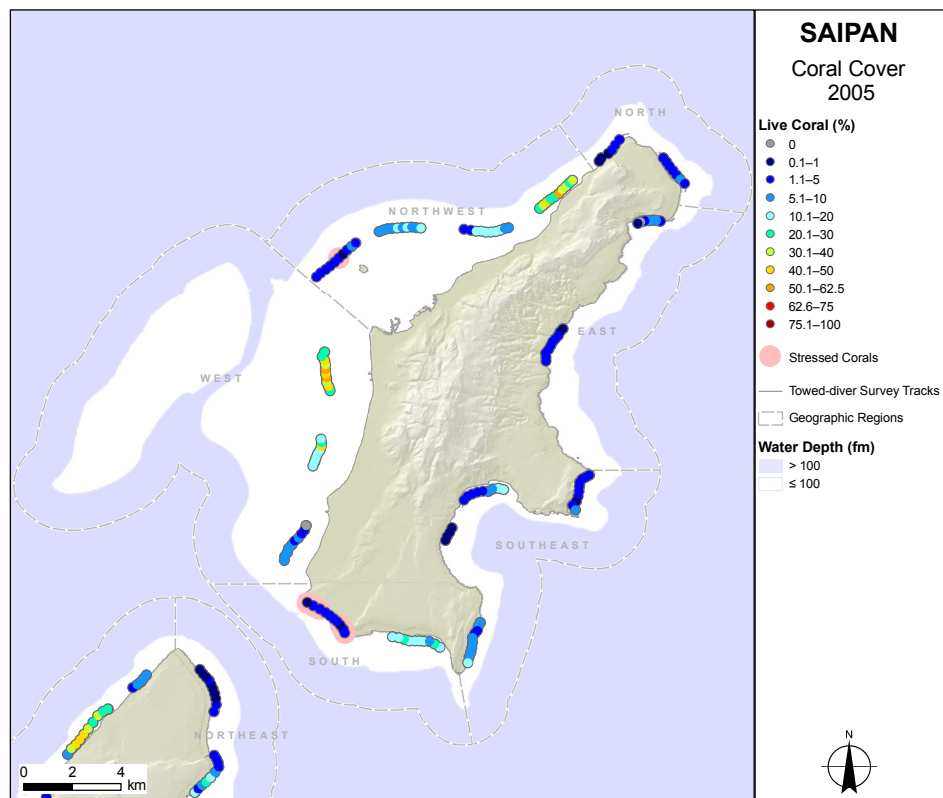


**Figure 8.5.1a.** Cover (%) observations of live hard corals from towed-diver benthic surveys of forereef habitats conducted at Saipan during MARAMP 2003. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of  $\sim 200 \times 10$  m ( $\sim 2000 \text{ m}^2$ ).



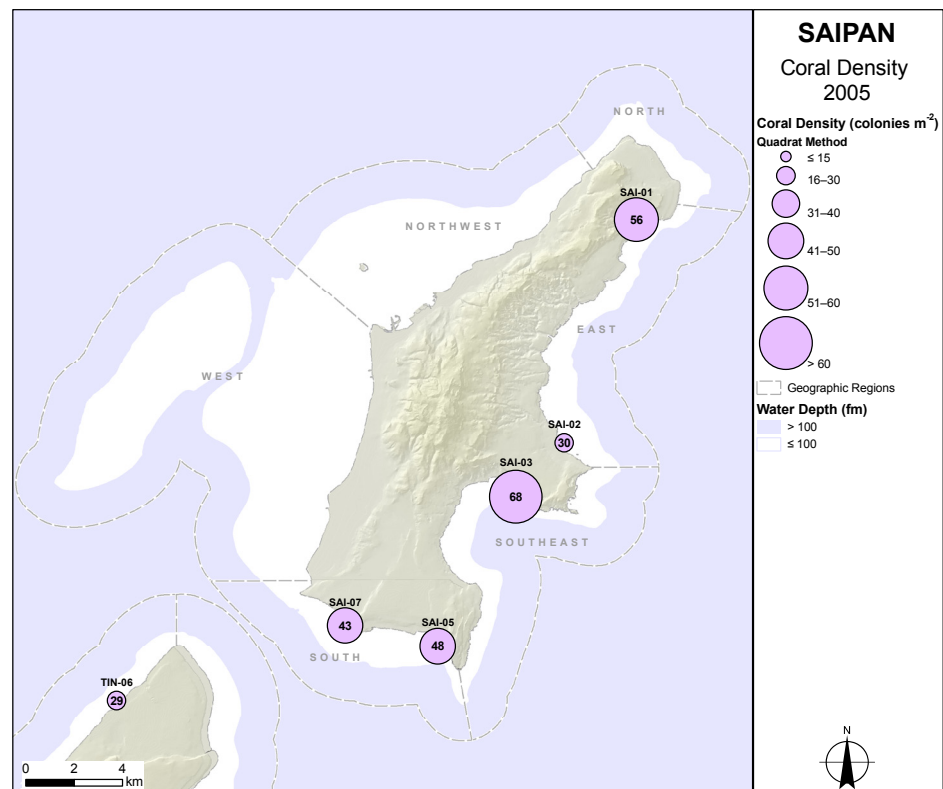
**Figure 8.5.1b.** Colony-density (colonies  $\text{m}^{-2}$ ) observations of live hard corals from REA benthic surveys of forereef habitats conducted at Saipan during MARAMP 2003. Values are provided within each symbol. The quadrat method was used in 2003 to assess coral-colony density.

**Figure 8.5.1c.** Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys of forereef habitats conducted around Saipan during MARAMP 2005. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of  $\sim 200 \times 10$  m ( $\sim 2000$  m<sup>2</sup>). Pink symbols represent segments where estimates of stressed-coral cover were  $> 10\%$ . Stressed-coral cover was measured as a percentage of overall coral cover in 2005.



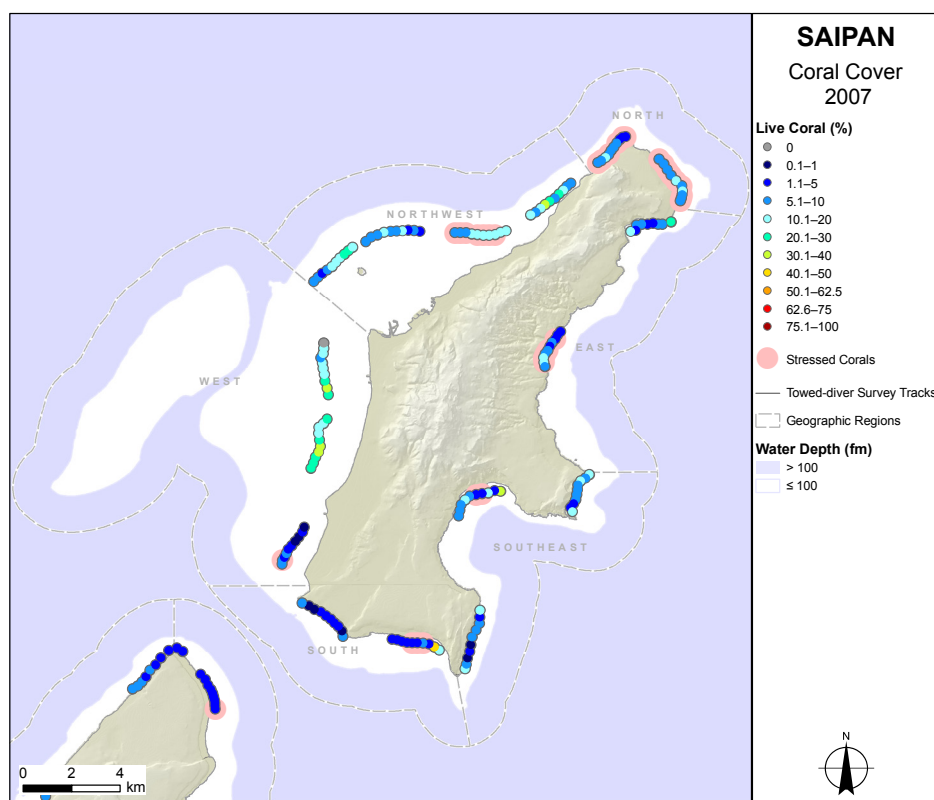
During MARAMP 2005, 5 REA benthic surveys using the quadrat method on forereef habitats at Saipan documented 963 coral colonies within a total survey area of 20 m<sup>2</sup>. Site-specific colony density ranged from 30 to 68.3 colonies m<sup>-2</sup> with an overall sample mean of 49 colonies m<sup>-2</sup> (SE 6.4). As in MARAMP 2003 surveys, the highest colony density was recorded at SAI-03 in the southeast region, and the lowest colony density was observed at SAI-02 in the east region near Puntan Halaihai (Fig. 8.5.1d).

**Figure 8.5.1d.** Colony-density (colonies m<sup>-2</sup>) observations of live hard corals from REA benthic surveys of forereef habitats conducted at Saipan during MARAMP 2005. Values are provided within each symbol. The quadrat method was used in 2005 to assess coral-colony density.



From MARAMP 2007 towed-diver surveys, mean cover of live hard corals on foreereef habitats around Saipan was 10% (SE 0.7). Coral cover was highest in the northwest and west regions with localized areas of high coral cover observed inshore of Lagunan Garupan in the west region with a mean of 25% for 13 segments and south of Puntan Makpè in the northwest region with a mean of 30% for 2 segments (Fig. 8.5.1e). Coral cover was relatively low in all other regions, except for 1 segment with coral cover of 35% in Bahia Laolao in the southeast region and 1 segment with coral cover of 45% west of Puntan I Naftan, the southernmost point of Saipan.

Overall, 6% (SE 0.6) of coral cover observed on foreereef habitats around Saipan appeared stressed in 2007 (see Chapter 2: “Methods and Operational Background,” Section 2.4.5, “Corals and Coral Disease). Stressed-coral cover was high in the north region around the northeast corner of Saipan (Fig. 8.5.1e) with a mean of 17% for 9 nonconsecutive segments. Stressed-coral cover was also noted in the north region near Puntan Sabaneta with a mean of 17% for 6 nonconsecutive segments, in the northwest region near Puntan Achugao with a mean of 21% for 7 nonconsecutive segments, and in the east region along Unai Talofo’fo’ with a mean of 19% for 5 nonconsecutive segments. All elevated levels of stressed-coral cover were recorded within a range of 10.1%–40%. Several other isolated areas of stressed-coral cover were noted in the southwest, south, and west regions.

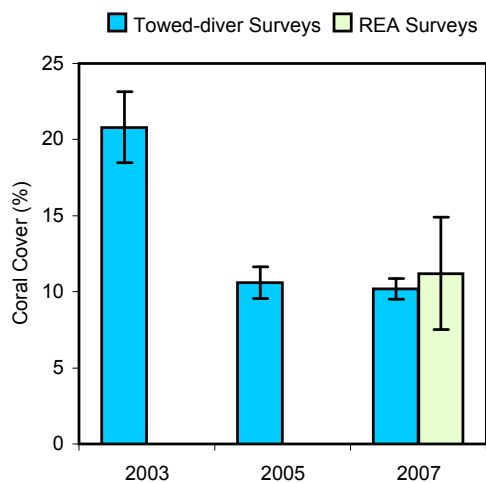
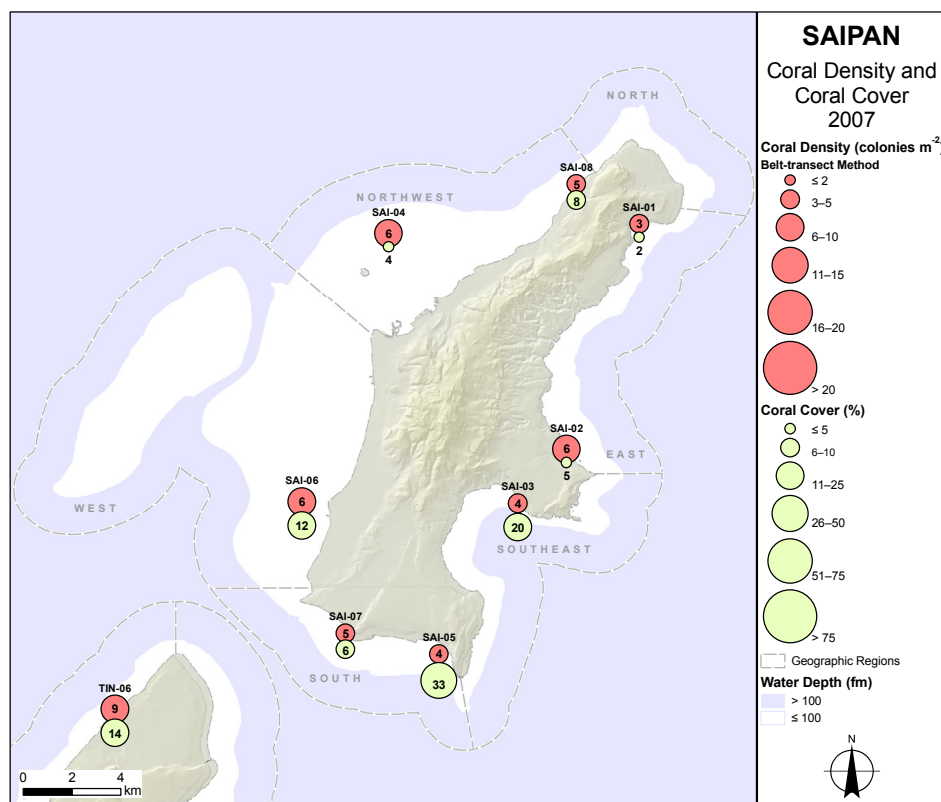


**Figure 8.5.1e.** Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys of foreereef habitats conducted around Saipan during MARAMP 2007. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of  $\sim 200 \times 10$  m ( $\sim 2000$  m<sup>2</sup>). Pink symbols represent segments where estimates of stressed-coral cover were > 10%. Stressed-coral cover was measured as a percentage of overall coral cover in 2007.

During MARAMP 2007, 8 REA benthic surveys using the line-point-intercept method were conducted on foreereef habitats around Saipan. Site-specific estimates of live-hard-coral cover from these surveys ranged from 2% to 33.3% (Fig. 8.5.1f) with an overall sample mean of 11.2% (SE 3.7). The highest coral cover of 33.3% was observed at SAI-05 in the south region west of Puntan Unai Opyan, and the lowest coral cover of 2% was found at SAI-01 in the northeast region in Bahia Fanonchuluyan.

During MARAMP 2007, 8 REA benthic surveys using the belt-transect method on foreereef habitats at Saipan documented 1929 coral colonies within a total survey area of 400 m<sup>2</sup>. Site-specific colony densities ranged from 2.6 to 6.4 colonies m<sup>-2</sup> with an overall sample mean of 4.8 colonies m<sup>-2</sup> (SE 0.5).

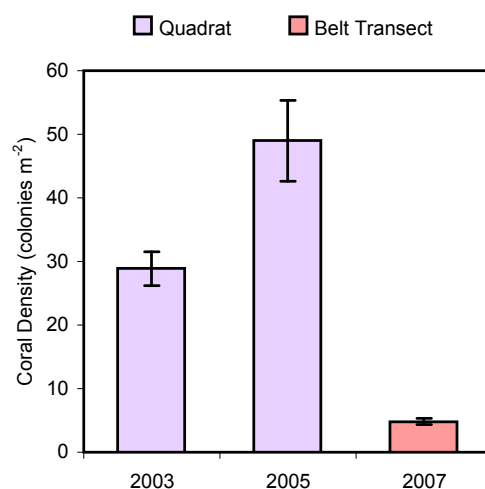
**Figure 8.5.1f.** Cover (%) and colony-density (colonies  $m^{-2}$ ) observations of live hard corals from REA benthic surveys of forereef habitats conducted around Saipan during MARAMP 2007. Values are provided within or below each symbol. The belt-transect method was used in 2007 to assess coral-colony density.



**Figure 8.5.1g.** Temporal comparison of mean live coral cover (%) from REA and towed-diver benthic surveys conducted on forereef habitats at Saipan during MARAMP 2003, 2005, and 2007. No REA surveys using the line-point-intercept method were conducted around Saipan in 2003 and 2005. Error bars indicate standard error ( $\pm 1$  SE) of the mean.

Islandwide mean cover of live corals estimated from towed-diver surveys of forereef habitats decreased from 21% (SE 2.3) in 2003 to 11% (SE 1) in 2005 but remained stable with 10% (SE 0.7) in 2007 (Fig. 8.5.1g). In close agreement with the overall mean from towed-diver surveys in 2007, site-specific estimates of coral cover averaged 11.2% (SE 3.7) for the 8 REA sites surveyed at Saipan in 2007 (Saipan was not surveyed for coral cover using the line-point-intercept method in 2003 or 2005). Although towed-diver surveys were more spatially limited in 2003 than in subsequent survey years, the survey tracks examined in 2003 were repeated in 2005 and 2007, and survey results reveal localized decreases in coral cover along those survey tracks (Figs. 8.5.1a, c, and e).

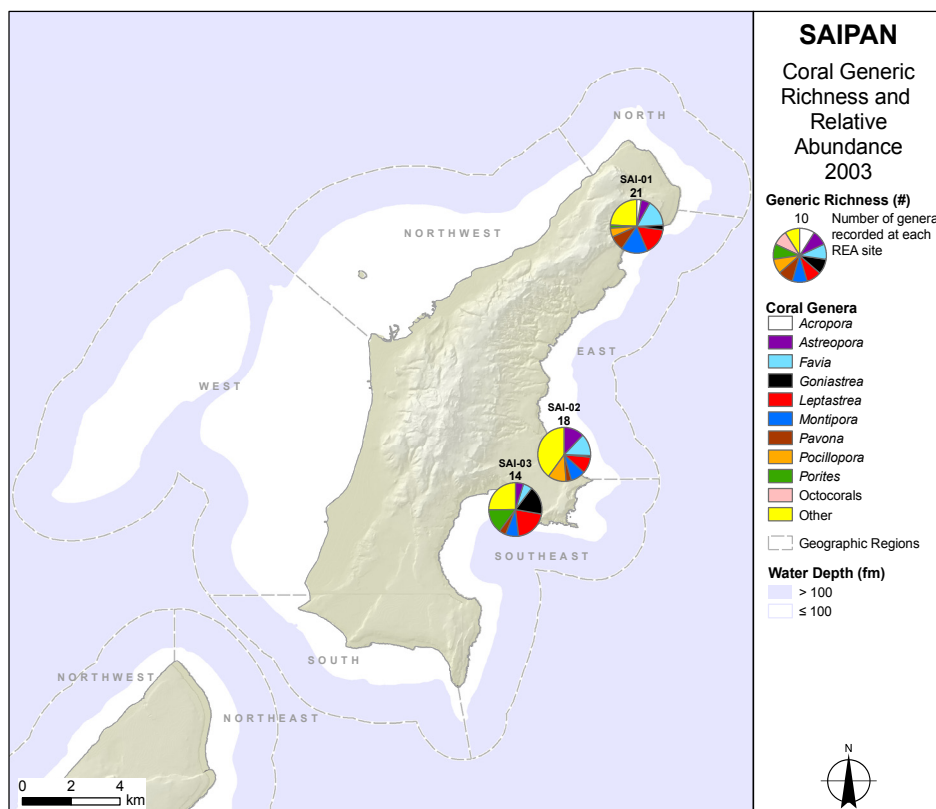
During MARAMP 2003 and 2005, REA benthic surveys of forereef habitats were conducted using the quadrat method around Saipan. Overall mean coral-colony density varied substantially between 2003 and 2005, increasing from 28.9 colonies  $m^{-2}$  (SE 2.6) in 2003 to 49 colonies  $m^{-2}$  (SE 6.4) in 2005 (Fig. 8.5.1h). At each of the 3 sites surveyed in both years (SAI-01, SAI-02, and SAI-03), colony density increased between 2003 and 2005. This increase likely is a result of recruitment, fragmentation of existing colonies, or both. Site-specific colony densities and the overall mean density of 4.8 colonies  $m^{-2}$  (SE 0.5) recorded during MARAMP 2007 were substantially lower than the colony densities observed in 2003 and 2005. However, this decline is likely an artifact of the use of a different method, the belt-transect method, to assess colony density in 2007. The method of placing quadrats used in 2003 and 2005 was highly biased towards surveying hard-bottom substrate where coral was present, whereas the belt-transect method used in 2007 assessed benthos that fell within the transect belts regardless of the nature of the substrate.



**Figure 8.5.1h.** Temporal comparison of mean coral-colony densities (colonies  $m^{-2}$ ) from REA benthic surveys conducted on forereef habitats at Saipan during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 and 2005 to measure coral-colony density, but the belt-transect method was used in 2007. Error bars indicate standard error ( $\pm 1$  SE) of the mean.

### Coral Generic Richness and Relative Abundance

Three REA benthic surveys of forereef habitats were conducted using the quadrat method at Saipan during MARAMP 2003. At least 25 coral genera were observed at Saipan. Generic richness ranged from 14 to 21 with a mean of 17.7 (SE 2) coral genera per site (Fig. 8.5.1i). The highest generic diversity was seen at SAI-01 in the east region in Bahia Fanonchuluyan, and the lowest generic diversity was recorded at SAI-03 in the southeast region.



**Figure 8.5.1i.** Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted at Saipan during MARAMP 2003. The pie charts indicate percentages of relative abundance of key coral genera. The quadrat method was used in 2003 to survey coral genera.

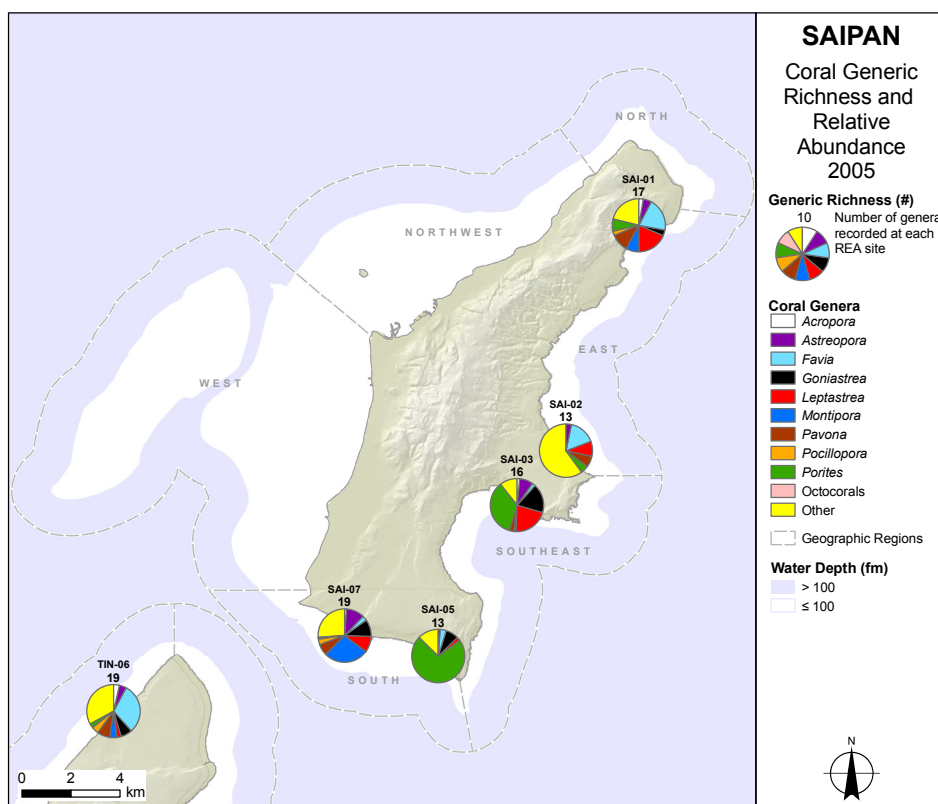


*Favia*, *Leptastrea*, and *Montipora* were the most numerically abundant genera, accounting for 11.7%, 15.5%, and 11.1% of the total number of colonies enumerated at Saipan during MARAMP 2003. All other genera individually accounted for < 10% of the total number of colonies. At SAI-01, *Favia*, *Leptastrea*, and *Montipora* all dominated the coral fauna (Fig. 8.5.1i), accounting for 16.2%, 16.2%, and 16.2% of the total number of observed colonies. *Favia* also dominated the coral fauna at SAI-02 in the east region near Puntan Halaihai, accounting for 13.3% of the total number of observed colonies. *Leptastrea* and *Goniastrea* dominated the coral fauna at SAI-03, accounting for 20.2% and 16.9% of the total number of observed colonies.

Five REA benthic surveys of forereef habitats were conducted using the quadrat method at Saipan during MARAMP 2005. At least 25 coral genera were observed at Saipan. Generic richness ranged from 13 to 19 with a mean of 15.6 (SE 1.2) coral genera per site (Fig. 8.5.1j). The highest generic diversity was seen at SAI-07 in the south region near Puntan Opyan, and the lowest generic diversity was recorded at SAI-02 in the east region and SAI-05 in the south region.

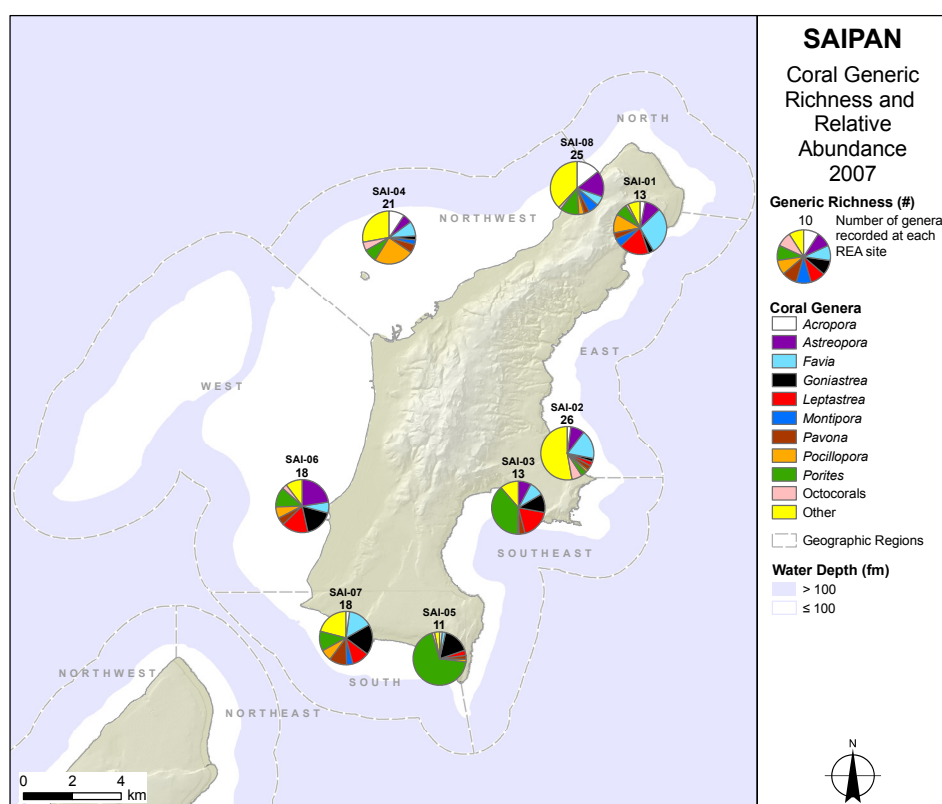
*Porites*, *Favia*, and *Leptastrea* were the most numerically abundant genera, accounting for 24.1%, 8.9%, and 12.1% of the total number of colonies enumerated at Saipan during MARAMP 2005. All other genera individually accounted for < 10% of the total number of observed colonies. *Porites* dominated the coral fauna at SAI-05 in the south region and SAI-03 in the southeast region (Fig. 8.5.1j), accounting for 71.7% and 34.8% of the total number of observed colonies. *Favia* dominated at SAI-01 and SAI-02, both in the east region, accounting for 20.2% and 15.8% of the total number of observed colonies. *Montipora* dominated at SAI-07 in the south region, accounting for 27.2% of the total number of observed colonies.

**Figure 8.5.1j.** Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted at Saipan during MARAMP 2005. The pie charts indicate percentages of relative abundance of key coral genera. The quadrat method was used in 2005 to survey coral genera.

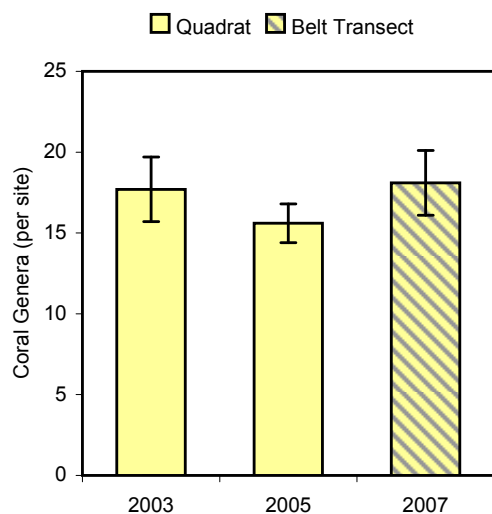


Eight REA benthic surveys of forereef habitats were conducted using the belt-transect method around Saipan during MARAMP 2007. At least 32 coral genera were observed, including the following 11 genera that had not been recorded at Saipan in 2003 or 2005: *Coscinaraea*, *Cycloseris*, *Euphyllia*, *Gardineroseris*, *Lobophytum*, *Millepora*, *Palythoa*, *Plesiastrea*, *Sarcophyton*, *Sinularia*, and an unidentified corallimorph. Generic richness ranged from 11 to 26 with a mean of 18.1 (SE 2) coral genera per site (Fig. 8.5.1k). The highest generic diversities were seen at SAI-02 and SAI-08 in the east and northwest regions, respectively, and the lowest generic diversity was recorded at SAI-05 in the south region.

*Porites* and *Favia* were the most numerically abundant genera, accounting for 20.1% and 11.6% of the total number of colonies enumerated around Saipan during MARAMP 2007. All other genera individually accounted for < 10% of the total number of observed colonies. Survey results show considerable variability among sites in coral dominance. *Porites* dominated the coral fauna at SAI-03 and SAI-05 in the southeast and south regions (Fig. 8.5.1k), accounting for 37.9% and 68.4% of the total number of colonies enumerated around Saipan. *Favia* dominated the coral fauna at SAI-01 and SAI-02 in the east region, accounting for 28.8% and 17.6% of the total number of observed colonies. *Astreopora* dominated the coral fauna at SAI-06, accounting for 22.3% of the total number of observed colonies. *Goniastrea* dominated the coral fauna at SAI-07 in the south region, accounting for 18.4% of the total number of observed colonies. *Pocillopora* dominated the coral fauna at SAI-04 in northwest region, accounting for 24.2% of the total number of observed colonies.



**Figure 8.5.1k.** Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted around Saipan during MARAMP 2007. The pie charts indicate percentages of relative abundance of key coral genera. The belt-transect method was used in 2007 to survey coral genera.



**Figure 8.5.11.** Temporal comparison of overall mean numbers of coral genera per site from REA benthic surveys conducted on forereef habitats at Saipan during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 and 2005 to survey coral genera, but the belt-transect method was used in 2007. Error bars indicate standard error ( $\pm 1$  SE) of the mean.

Site-specific estimates of generic richness across the 3 MARAMP survey years ranged from 11 to 26 on forereef habitats at Saipan. Site-specific and overall mean generic-richness values (Fig. 8.5.11) were higher in 2007 with a mean of 18.1 (SE 2) coral genera per site than in 2003 and 2005 with means of 17.7 (SE 2) and 15.6 (SE 1.2) coral genera per site. Note the difference in the size of the area in which corals were censused: the survey area at each site in 2007 was 50 m<sup>2</sup> per site, an area much larger than the 3.75 and 4 m<sup>2</sup> per site surveyed in 2003 and 2005 (see Chapter 2: “Methods and Operational Background,” Section 2.4.5, “Corals and Coral Disease”). Additionally, the only octocoral genus assessed in 2003 and 2005 was *Heliopora*, whereas all octocoral genera were assessed in 2007.

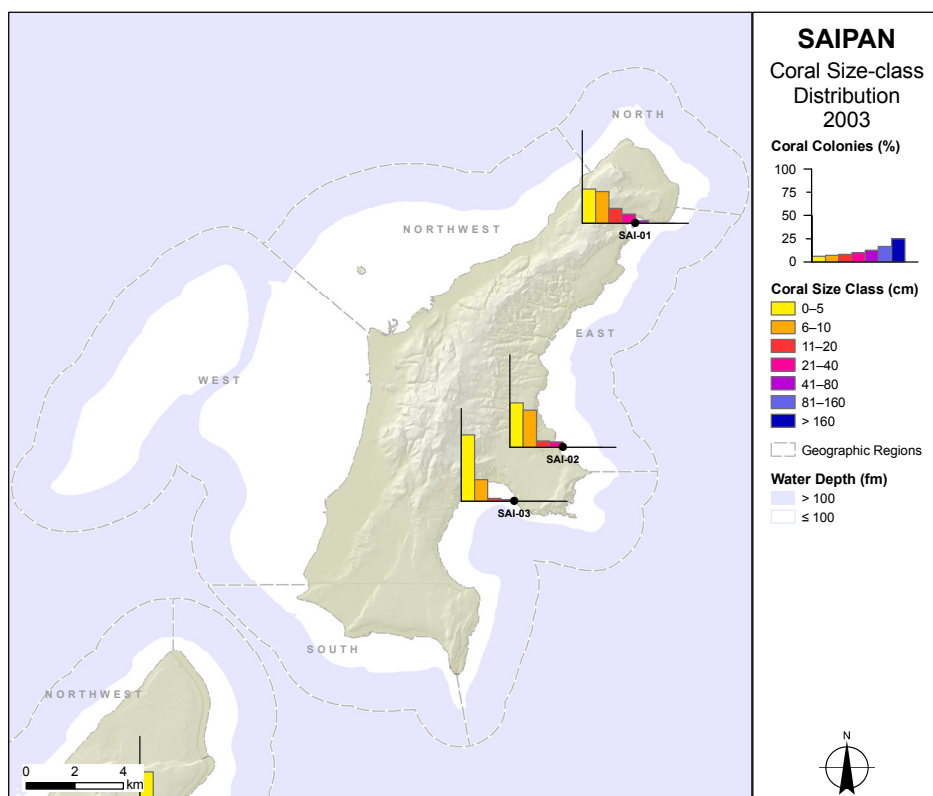
During the 3 MARAMP survey years, 38 coral genera were observed on forereef habitats at Saipan. *Favia*, *Porites*, *Leptastrea*, and *Montipora* were important components of the coral fauna around this island. *Favia* was the most numerically abundant taxon in 2003 and the second-most abundant in 2005 and 2007, accounting for 11.7%, 8.9%, and 11.6% of the total number of colonies enumerated at Saipan. *Porites* was the most numerically abundant taxon in 2005 and 2007, accounting for 24.1% and 20.1% of the total number of colonies. *Leptastrea* was the second-most numerically abundant taxon in 2003 and the third-most abundant in 2005, accounting for 15.5% and 12.1% of the total number of colonies. *Montipora* contributed 11.1% of the total number of observed colonies in 2003. All other taxa contributed < 10% of the total number of observed colonies across the 3 survey years.

### Coral Size-class Distribution

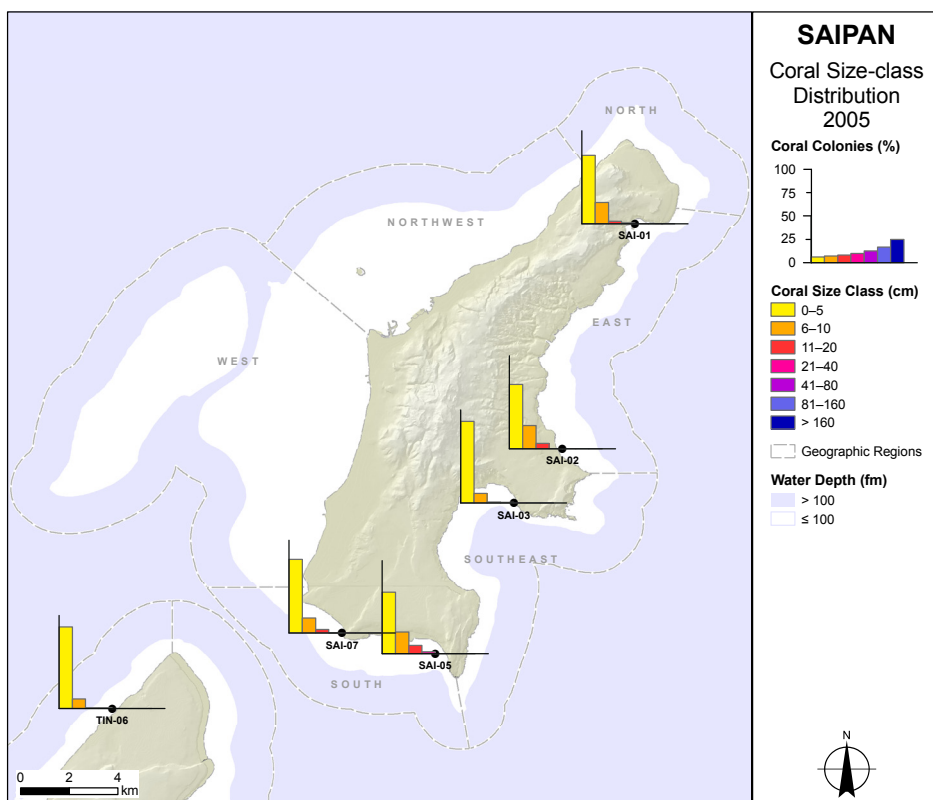
During MARAMP 2003, 3 REA benthic surveys of forereef habitats were conducted at Saipan using the quadrat method. The coral size-class distribution from these surveys shows that the majority (52.2%) of corals had maximum diameters  $\leq 5$  cm (Fig. 8.5.1m). The next 4 size classes (6–10, 11–20, 21–40, and 41–80 cm) accounted for 32.5%, 8.7%, 5.7%, and 0.9% of colonies recorded at Saipan. At all 3 sites, SAI-01, SAI-02, and SAI-03, a high proportion of colonies were small ( $\leq 10$  cm), accounting for 71.2%, 87.8%, and 95.2% of colonies observed. A correspondingly low proportion (26.1%, 12.2%, and 4.8%) of observed colonies was midsize (11–40 cm) at these 3 sites. Large ( $> 40$  cm) colonies were recorded only at SAI-01 in the east region.

During MARAMP 2005, 5 REA benthic surveys of forereef habitats were conducted at Saipan using the quadrat method. The coral size-class distribution from these surveys shows that the majority (75.2%) of corals had maximum diameters  $\leq 5$  cm (Fig. 8.5.1n). The next 3 size classes (6–10, 11–20, and 21–40 cm) accounted for 19.4%, 4.5%, and 0.9% of colonies recorded at Saipan. No colonies with maximum diameters  $> 40$  cm were recorded. At each site, the majority ( $> 65\%$ ) of corals were in the smallest ( $\leq 5$  cm) size class.

During MARAMP 2007, 8 REA benthic surveys of forereef habitats were conducted around Saipan using the belt-transect method. The coral size-class distribution from these surveys shows that the majority (76.3%) of corals had maximum diameters  $\leq 10$  cm (Fig. 8.5.1o). The first 4 size classes (0–5, 6–10, 11–20, and 21–40) accounted for 39%, 37.3%, 14.2%, and 6.9% of colonies recorded around Saipan, and colonies with maximum diameters  $> 40$  cm accounted for 2% of colonies observed. The highest proportions (28.8% and 31.1%) of midsize (11–40 cm) colonies were found at SAI-02 and SAI-05 in the east and south regions, and the highest proportions (96.2% and 91.9%) of small ( $\leq 10$  cm) colonies were observed at SAI-01 and SAI-07 in the east and south regions.

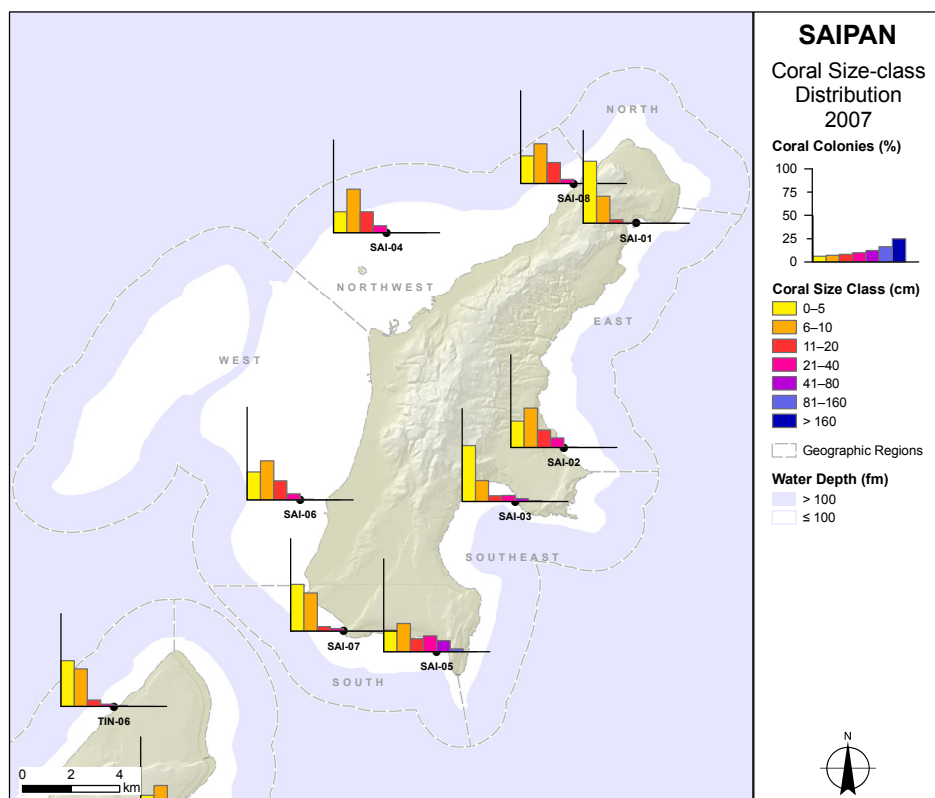


**Figure 8.5.1m.** Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted at Saipan during MARAMP 2003. The observed size classes are color coded in a size-frequency chart at each REA site. The quadrat method was used in 2003 to size corals.



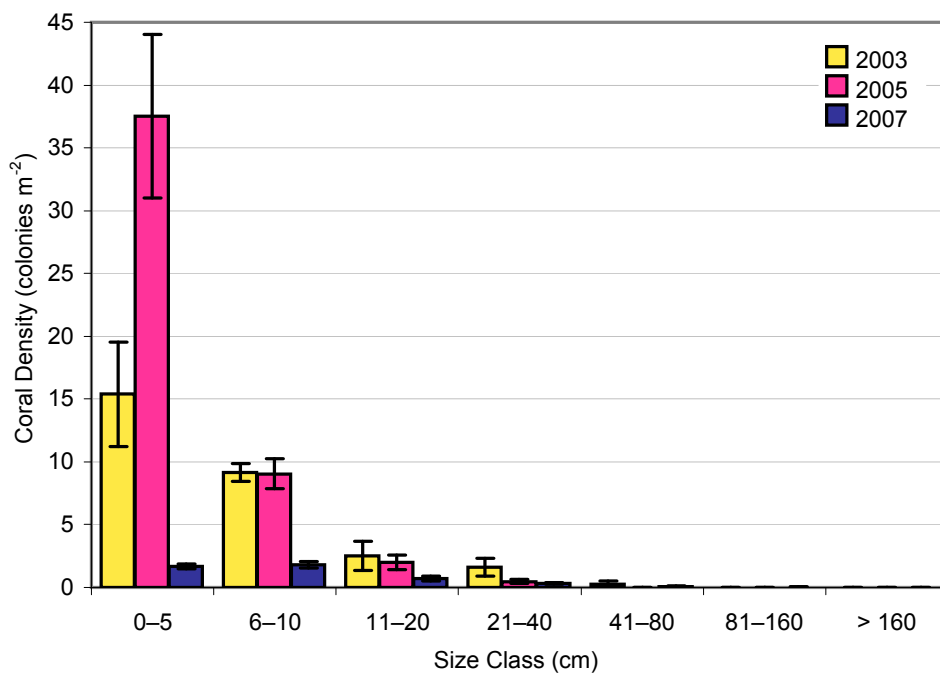
**Figure 8.5.1n.** Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted at Saipan during MARAMP 2005. The observed size classes are color coded in a size-frequency chart at each REA site. The quadrat method was used in 2005 to size corals.

**Figure 8.5.1o.** Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted around Saipan during MARAMP 2007. The observed size classes are color coded in a size-frequency chart at each REA site. The belt-transect method was used in 2007 to size corals.



Site-specific and overall distribution of estimated coral size classes on forereef habitats at Saipan are affected by inherent biases in the methods used to census and size corals. During MARAMP 2003 and 2005, corals whose center fell within the borders of a quadrat ( $50 \times 50$  cm) were tallied and measured in 2 planar dimensions to the nearest centimeter. Fewer large colonies than small colonies can fall within a quadrat. This bias can contribute to higher counts of colonies in the smallest size classes and lower counts of colonies in the largest size classes compared to the actual relative colony densities. At each site, 15 or 16 such quadrats were examined (total survey area =  $3.75$  or  $4$  m<sup>2</sup>), enabling observers to closely inspect and record each coral colony within a quadrat. During MARAMP 2007, corals whose center fell within a belt transect ( $1 \times 25$  m) were tallied and binned into 1 of 7 size classes based on visual estimates of maximum colony diameter. This method is better suited to capturing large colonies, but the larger census area likely reduces the number of very small

**Figure 8.5.1p.** Mean coral-colony densities (colonies m<sup>-2</sup>) by size class from REA benthic surveys of forereef habitats conducted at Saipan during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 and 2005 to size corals, but the belt-transect method was used in 2007. Error bars indicate standard error ( $\pm 1$  SE) of the mean.





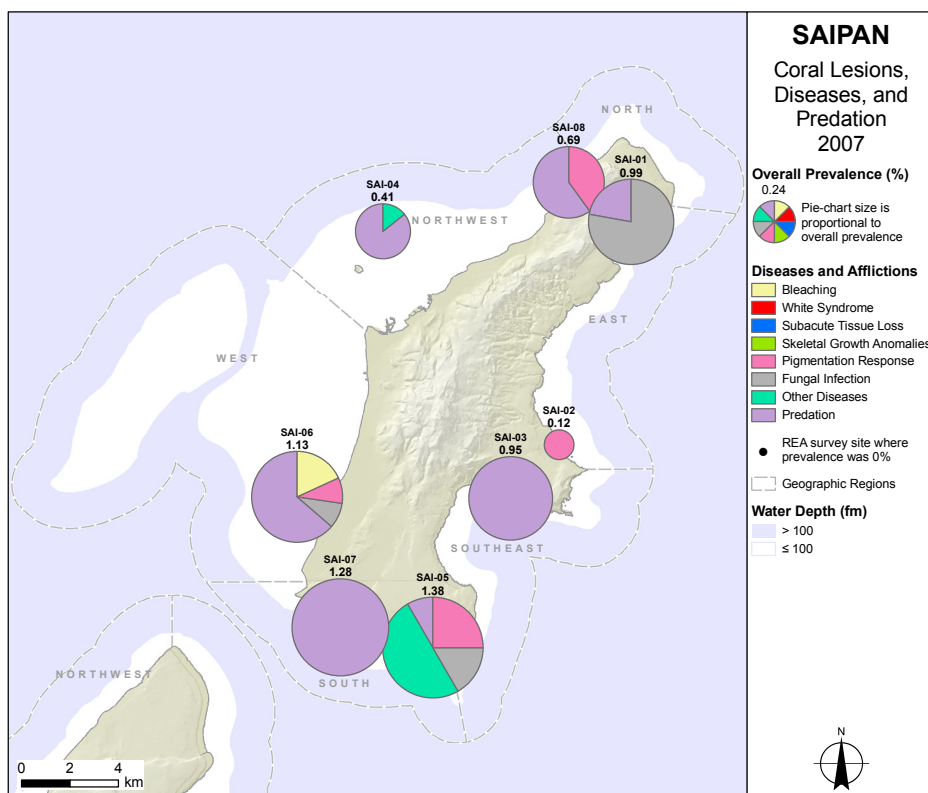
( $\leq 5$  cm) colonies that are observed and recorded. For more on these survey methods, see Chapter 2: “Methods and Operational Background,” Section 2.4.5, “Corals and Coral Disease.”

These methodological biases are reflected in the size-class data by survey year. Data from both 2003 and 2005 show that most coral colonies were in the smallest size class (Fig. 8.5.1p). In 2003 and 2005, more than half (52.2% and 75.2%) of all colonies censused on forereef habitats at Saipan had a maximum diameter  $\leq 5$  cm, but in 2007 only 39% of colonies were in this smallest size class. Comparing size-class data between survey years when different methods were used is, therefore, inappropriate. Only SAI-01, SAI-02, and SAI-03 in the east and southeast regions were surveyed with the same quadrat method during 2 different survey years, MARAMP 2003 and 2005. At all 3 sites between these survey years, the proportion of colonies in the smallest size class ( $\leq 5$  cm) increased substantially, and the proportion of colonies in other size classes decreased, suggesting that either increased recruitment, colony fragmentation, or both occurred during this period.

## 8.5.2 Surveys for Coral Disease and Predation

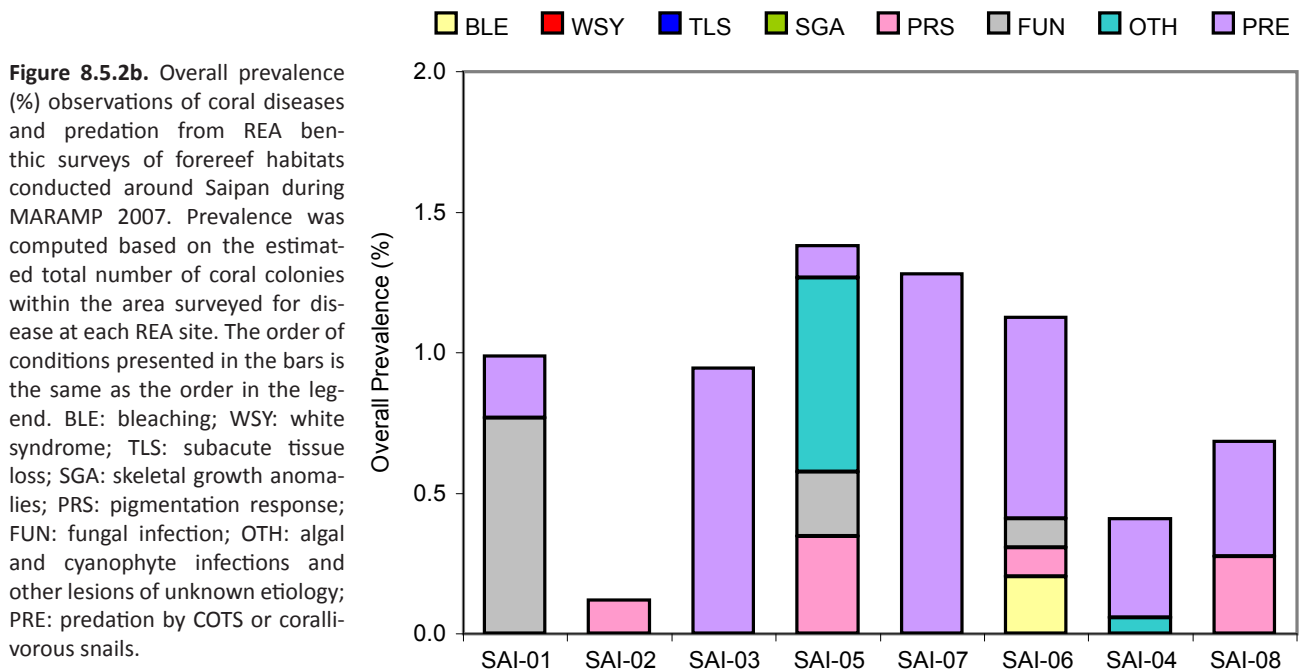
During MARAMP 2007, REA benthic surveys for coral disease and predation were conducted using the belt-transect method at 8 sites on forereef habitats around Saipan, covering a total area of more than 2200 m<sup>2</sup>. Coral disease at Saipan was recorded with a mean overall prevalence of 0.4% (SE 0.2), excluding predation. Four major disease conditions were registered at Saipan: bleaching, pigmentation response, fungal infections, and other syndromes of unknown etiology. Of the 6 sites that contained disease, SAI-01 and SAI-05 in the east and south regions exhibited the greatest overall prevalence values of 0.8% and 1.3% (Figs. 8.5.2a and b; the values of overall prevalence shown in this Figure 8.5.2a include predation). Pigmentation response on *Porites* was the most numerous disease condition, accounting for 40% of cases with an overall prevalence of 0.1% at Saipan.

Lesions involving fungal infections were the second-most abundant disease state, accounting for 27% of disease cases. These types of lesions, with an overall prevalence value of 0.8%, were detected mostly at SAI-01 in the east region in Bahia Fanonchuluyan. Additionally, bleaching conditions were quite low with an overall mean prevalence of 0.03% (SE 0.03), and affected colonies were observed primarily at SAI-06 in the west region. Bleaching was mild, focal, and observed on corals of the genus *Platygyra*. Other coral diseases present around Saipan included algal and cyanophyte infections, as well as syndromes of unknown etiology. These were sporadic and occurred at a low mean overall prevalence of 0.09% (SE 0.09) on corals of the genera *Porites* and *Pocillopora*.



**Figure 8.5.2a.** Overall prevalence (%) observations of coral diseases and predation from REA benthic surveys of forereef habitats conducted around Saipan during MARAMP 2007. Prevalence was computed based on the estimated total number of coral colonies within the area surveyed for disease at each site. The color-coded portions of the pie charts indicate disease-specific prevalence.

Cases of coral predation attributable to COTS or corallivorous snails, such as snails from the genus *Drupella*, were observed at all sites except for SAI-02 on the east region near Puntan Halaihai. The greatest levels of predation were registered at SAI-07 and SAI-03 in the south and southeast regions (Fig. 8.5.2b). The coral genera *Porites*, *Pocillopora*, and *Stylophora* were the main prey of COTS and snails. For more about COTS around Saipan, see Section 8.7: “Benthic Macroinvertebrates.”



## 8.6 Algae and Algal Disease

### 8.6.1 Algal Surveys

#### *Algal Cover: Macroalgae and Turf Algae*

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on forereef habitats at the island of Saipan was 49% (SE 2.9). Observations of macroalgal cover in 2003 included both macroalgae and turf algae. The survey with the highest mean macroalgal cover of 78%, within a range of 40.1%–100%, occurred in the north region (Fig. 8.6.1a, top left panel). Habitats in this area were primarily composed of continuous spur-and-groove formations of medium-low to medium complexity. The second-greatest mean macroalgal cover of 56% was recorded in the southeast region along the spur-and-groove reefs to the south of Tuteuram in Bahia Laolao, where habitat complexity ranged from medium to medium-high (for place-names and their locations, see Figure 8.2a in Section 8.2: “Survey Effort”). Surveys along the pavement reefs of Unai Talofofo in the east region and the area between Puntans Laolao Kattan and Hakmang in the southeast region reported mean macroalgal cover of 54% and 52%. Habitat complexity in these areas was primarily medium, interspersed occasionally with more complex areas of large rock boulders. The survey conducted in Bahia Fanonchuluyan in the east region found a mean macroalgal cover of 35% and habitats of primarily pavement or continuous reef of medium to high complexity.

During MARAMP 2003 and a subsequent deployment in 2004, 54 TOAD surveys were conducted off Saipan Harbor and Garapan Anchorage in depths  $\leq 140$  m. Analyses of TOAD video footage suggest that macroalgal cover was low in this area, at least as seen in images. Where macroalgae were observed in a given video frame, macroalgal cover was predominantly  $\leq 40\%$  (Fig. 8.6.1a, top left panel). A small number of isolated patches of relatively high cover were observed within the anchorage areas at depths of 10–140 m.

From MARAMP 2005 towed-diver surveys, mean cover of macroalgae on forereef habitats around Saipan was 31% (SE 2). The survey with the highest mean macroalgal cover of 69%, within a range of 62.6%–75%, occurred south of Tuteuram

within Bahia Laolao in the southeast region (Fig. 8.6.1a, middle left panel). Also in the southeast region, the surveys conducted south of Puntan Dandan and between Puntans Laolao Kattan and Hakmang reported higher than average macroalgal cover of 52% and 46%. The habitat in these areas was primarily pavement of medium-low to medium complexity. All 6 surveys conducted in the north and northwest regions also reported relatively high values of macroalgal cover. The surveys conducted immediately south of Puntan Sabaneta, the northernmost point of Saipan, and northwest of Isleta Managaha near SAI-04 reported the greatest cover in the northwest region with 65% and 61%, respectively, and were characterized as low to medium complexity pavement or rock reefs. The lowest macroalgal cover generally were found in the south and west regions.

From MARAMP 2007 towed-diver surveys, mean cover of macroalgae on forereef habitats around Saipan was 32% (SE 1.6). The survey with the highest mean macroalgal cover of 68%, within a range of 50.1%–75%, occurred northwest of Isleta Managaha in the northwest region (Fig. 8.6.1a, bottom left panel). Habitat in this area predominantly consisted of continuous, gently sloping reef of medium-low complexity. Species of the green algal genus *Halimeda* and brown algal genus *Padina* dominated this substrate, along with species of the red algal genus *Asparagopsis*. Other areas of high macroalgal cover were observed during the 2 surveys conducted in the north region, to the south and east of Puntan Sabaneta, where 52% and 62% of the benthos was dominated by species of the green algae *Microdictyon* and *Halimeda* and the brown alga *Padina*, along with species of the red algal genus *Liagora*. Habitats here were primarily characterized as pavement or rock with complexity ranging from medium-low to medium-high. Reefs in the east region all hosted slightly higher than average values of macroalgal cover. In contrast, in the southeast region, the survey conducted between Puntans Laolao Kattan and Hakmang recorded mean macroalgal cover of 21%, within a range of 5.1%–40%. Pavement reef of medium-low complexity was the predominant habitat type, except in areas where sand prevailed.

During MARAMP 2007, 8 REA benthic surveys of forereef habitats around Saipan were conducted using the line-point-intercept method. Site-specific estimates of macroalgal cover ranged from 0% to 36.3% with an overall mean of 11% (SE 4.4). The survey with the highest macroalgal cover of 36.3% occurred in the northwest region at SAI-08 (Fig. 8.6.1b). Relatively high macroalgal cover was also found at the other REA site in the northwest region, SAI-04, with 21.6%. No macroalgae were recorded in the southeast region at SAI-03.

Turf-algal cover from these REA benthic surveys in 2007 ranged from 20.6% to 79.4% with an overall mean of 60% (SE 7.1). The survey with the highest turf-algal cover of 79.4% occurred in the east region at SAI-02 (Fig. 8.6.1b). Relatively high levels of turf-algal cover were also found in the south region at SAI-07 with 73.5%, in the east region at SAI-01 with 72.5%, and in the west region at SAI-06 with 70.6%. The lowest turf-algal cover of 20.6% was recorded in the southeast region at SAI-03.

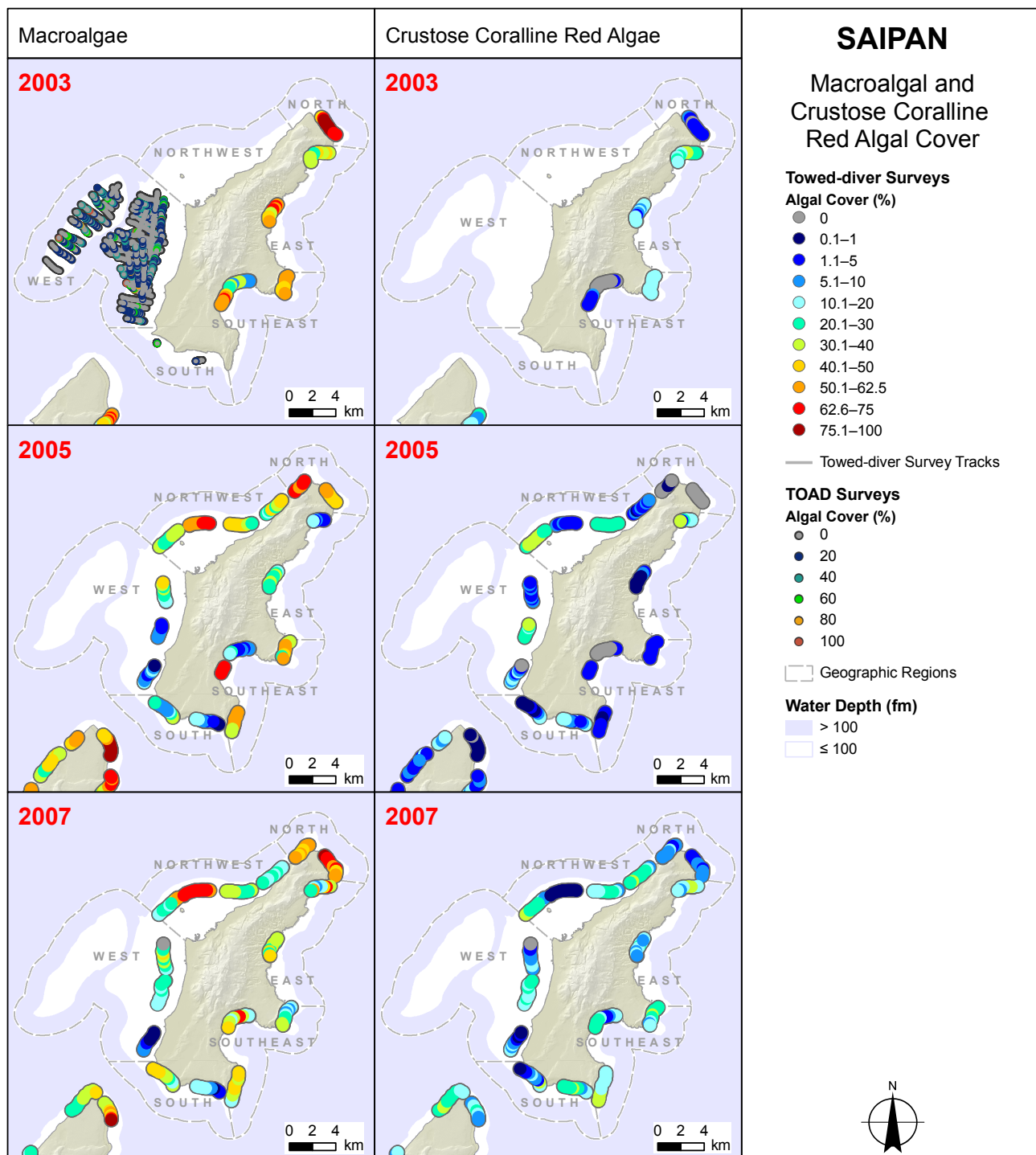
### **Algal Cover: Crustose Coralline Red Algae**

From MARAMP 2003 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats at Saipan was 10% (SE 1.2). The survey with the highest mean crustose-coralline-red-algal cover of 24%, within a range of 10.1%–40%, occurred in Bahia Fanonchuluyan (Fig. 8.6.1a, top right panel), where the habitat consisted of pavement and continuous reef of medium to high complexity. The surveys conducted in the vicinity of Unai Talofo'fo' in the east region and in the southeast region between Puntans Laolao Kattan and Hakmang reported greater than average values for cover of crustose coralline red algae of 12% and 15%, respectively. Habitats in these areas had medium complexity and consisted of pavement with rock boulders. The remaining survey areas, characterized by spur-and-groove formations or continuous reef, reported low cover of < 4%.

From MARAMP 2005 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Saipan was 9% (SE 0.9). The survey with the highest mean crustose-coralline-red-algal cover of 32%, within a range of 20.1%–40%, occurred on the forereef off Isleta Managaha (Fig. 8.6.1a, middle right panel), where the habitat consisted of continuous reef of medium-low to medium complexity. The surveys conducted in the northwest region near Puntan Achugao and in the west region north of Puntan Susupi reported cover values for crustose coralline red algae of 25%. Both habitats were characterized as gently sloping, continuous reefs of medium-low to medium complexity. All remaining surveys around Saipan reported below average cover values, including 0% cover in the north region.

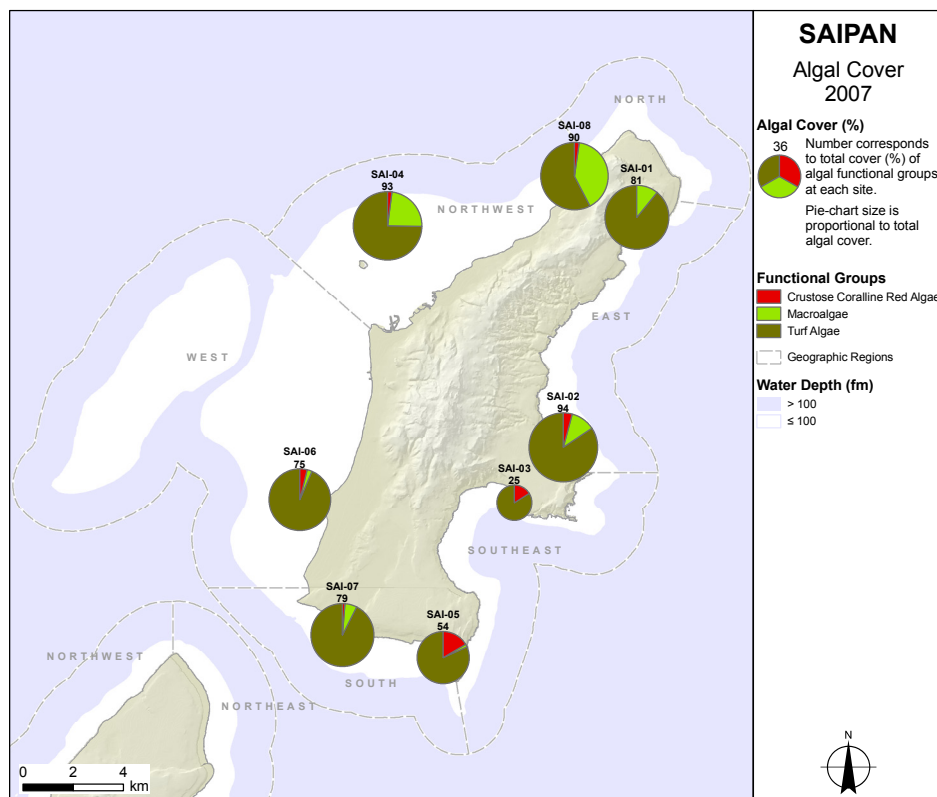
From MARAMP 2007 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Saipan was 15% (SE 0.8). The survey with the highest mean crustose-coralline-red-algal cover of 24%, within a range of 5.1%–40%, occurred on the forereef off Isleta Managaha (Fig. 8.6.1a, bottom right panel), where the habitat consisted of con-

tinuous reef of medium-low to medium complexity. Higher than average cover values for crustose coralline red algae with means of 19%–23% were reported for 7 other survey areas: including the northwest region near Puntans Achugao and Makpè, in the east region near Bahia Fanonchuluyan, in the southeast region between Puntans Laolao Kattan and Hakmang and north of Puntan I Naftan, in the south region near Puntan Unai Opyan, and the area to the north of Puntan Susupi.





During MARAMP 2007, 8 REA benthic surveys of forereef habitats around Saipan were conducted using the line-point-intercept method. Site-specific estimates of crustose-coralline-red-algal cover ranged from 0% to 8.8% with an overall mean of 3% (SE 1). The survey with the highest crustose-coralline-red-algal cover of 8.8% occurred in the south region at SAI-05 (Fig. 8.6.1b). No crustose coralline red algae were recorded at SAI-01 in the east region. Many surveys had crustose-coralline-red-algal cover of  $\leq 2\%$ , including SAI-04 with 2%, SAI-08 with 2%, and SAI-07 with 1%.



**Figure 8.6.1b.** Observations of algal cover (%) from REA benthic surveys of forereef habitats conducted using the line-point-intercept method around Saipan during MARAMP 2007. The pie charts indicate algal cover by functional group, and values of total cover are provided above each symbol.

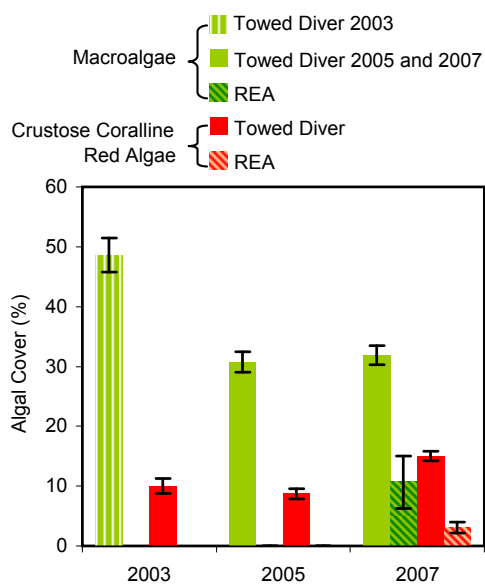
### Algal Cover: Temporal Comparison

Between MARAMP 2005 and 2007, islandwide mean cover of macroalgal populations at Saipan, based on towed-diver surveys of forereef habitats, essentially did not change (Fig. 8.6.1c). In general, macroalgae most commonly inhabited pavement of low-to-medium complexity, and the most common macroalgal genera were the green algae *Halimeda* and *Microdictyon*, the brown alga *Padina*, and the red algae *Asparagopsis* and *Liagora*. When considering survey results, keep in mind that turf algae were included, along with macroalgae, in towed-diver surveys of macroalgal cover only in 2003 (for information about data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”).

From MARAMP 2005 to 2007, 3 substantial differences occurred along reefs in the east region. Macroalgal cover increased by 26% and 29% in the surveys of Bahia Fanonchuluyan and Bahia Laolao, returning to levels similar to those values observed in 2003. Inversely, a 25% decrease occurred between MARAMP 2005 and 2007 in surveys completed between Puntans Laolao Kattan and Hakmang in the southeast region.

Populations of crustose coralline red algae at Saipan, based on towed-diver surveys of forereef habitats, varied as much as 6% in average cover of the benthos between MARAMP survey years. One factor contributing to differences in cover levels is a change in survey effort: MARAMP 2003 surveys were conducted only in the north, east, and southeast regions, and MARAMP 2005 and 2007 surveys were conducted in all 5 regions. Crustose coralline red algae most commonly inhabited medium to medium-high complexity regions of greater structure than typical macroalgal habitats.





**Figure 8.6.1c.** Temporal comparison of algal-cover (%) values from surveys conducted on forereef habitats at Saipan during MARAMP 2003, 2005, and 2007. Values of macroalgal cover from towed-diver surveys include turf algae only in 2003; surveys were conducted only in the north, east, and southeast regions in 2003 but in all regions in 2005 and 2007. No REA surveys using the line-point-intercept method were conducted at Saipan in 2003 and 2005. Error bars indicate standard error ( $\pm 1$  SE) of the mean.

### Macroalgal Genera and Functional Groups

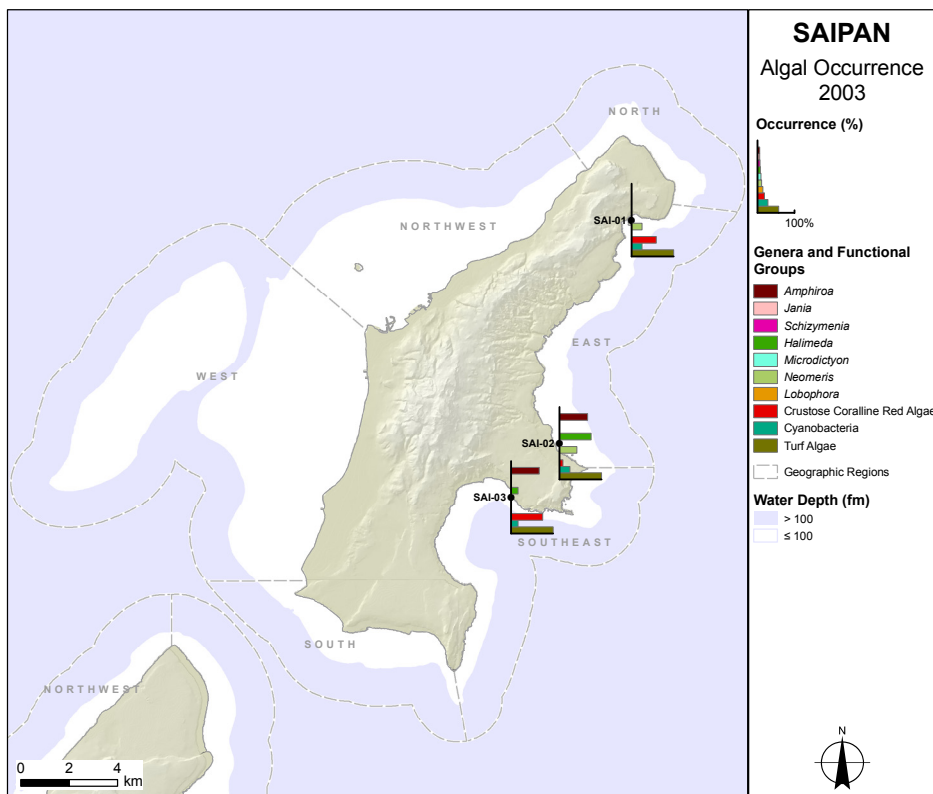
In the field, because of their small size or similarity in appearance, turf algae, crustose coralline red algae, cyanophytes (blue-green algae), and branched, nongeniculate coralline red algae were lumped into functional group categories. The generic names of macroalgae from field observations are tentative, since microscopic analysis is necessary for proper taxonomic identification. The lengthy process of laboratory-based taxonomic identification of all algal species collected at REA sites has not been undertaken yet for the southern islands of the Mariana Archipelago. Ultimately, based on microscopic analysis that may be done in the future, the generic names of macroalgae reported in this section may change and algal diversity reported for each REA site likely will increase.

During MARAMP 2003, REA benthic surveys were conducted at 3 sites on forereef habitats at Saipan. In the field, 13 macroalgal genera (7 red, 4 green, and 2 brown), containing at least 16 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. SAI-02 in the east region had the highest macroalgal generic diversity with 9 genera, containing 10 species, documented in the field. The lowest generic diversity was found at SAI-01 in Bahia Fanonchuluyan in the northeast region with only 3 species representing 2 genera recorded.

Species of the calcified macroalgae *Amphiroa* and *Halimeda* were the most common components of algal communities at Saipan in 2003 (Fig. 8.6.1d), occurring in 44% and 30.1% of sampled photoquadrats. Although neither of these 2 genera was found at SAI-01, they occurred in 67%–92% and 17%–83% of sampled photoquadrats at SAI-02 in the east region and SAI-03 in the southeast region. Of the 16 taxa tentatively identified to species level, only 5 occurred at SAI-01, making distinctive spatial patterns of distribution difficult to determine for most macroalgae at Saipan. The greatest diversity was recorded at SAI-02 with 10 distinct species. This site was dominated by species of the green algae *Halimeda* and *Neomeris* and the red alga *Amphiroa*, occurring in 83%, 42%, and 67% of sampled photoquadrats; 5 other taxa occurred in  $\leq 16\%$  of sampled photoquadrats. Species of the genus *Neomeris* occurred in 25% and 42% of sampled photoquadrats at SAI-01 and SAI-02 but not at all at SAI-03, which was populated predominantly by species of *Amphiroa*. At the northernmost site in the east region, SAI-01, *Neomeris* was the second-most abundant genus next to *Tricleocarpa* which occurred in 67% of sampled photoquadrats, but only occurred in 8% of photoquadrats at SAI-02 and SAI-03.

The observed overall mean cover of crustose coralline red algae essentially remained the same between MARAMP 2003 and 2005 (Fig. 8.6.1c). The greatest variability, with decreases of 11%–12%, in mean cover between these survey years was recorded in the 3 surveys conducted in Bahia Fanonchuluyan, along Unai Talofo'fo', and between Puntans Laolao Kattan and Hakmang. Later, between MARAMP 2005 and 2007, islandwide mean cover of crustose coralline red algae increased 6%, although all surveys conducted south of Puntan Achugao in the west and southwest regions reported decreases in cover of as much as 8%. The highest changes were observed in the southeast region between Puntans Laolao Kattan and Hakmang and northeast of Puntan I Naftan where cover increased by 19% and 20.8%.

Turf algae, crustose coralline red algae, and cyanobacteria were all common in 2003, occurring in 100%, 47%, and 22% of photoquadrats sampled at Saipan (Fig. 8.6.1d). Although crustose coralline red algae were observed at all sites, the occurrence of this functional group varied broadly with observations recorded in 8%–75% of sampled photoquadrats. Cyanobacteria occurred in 17%–25% of the photoquadrats sampled at Saipan.



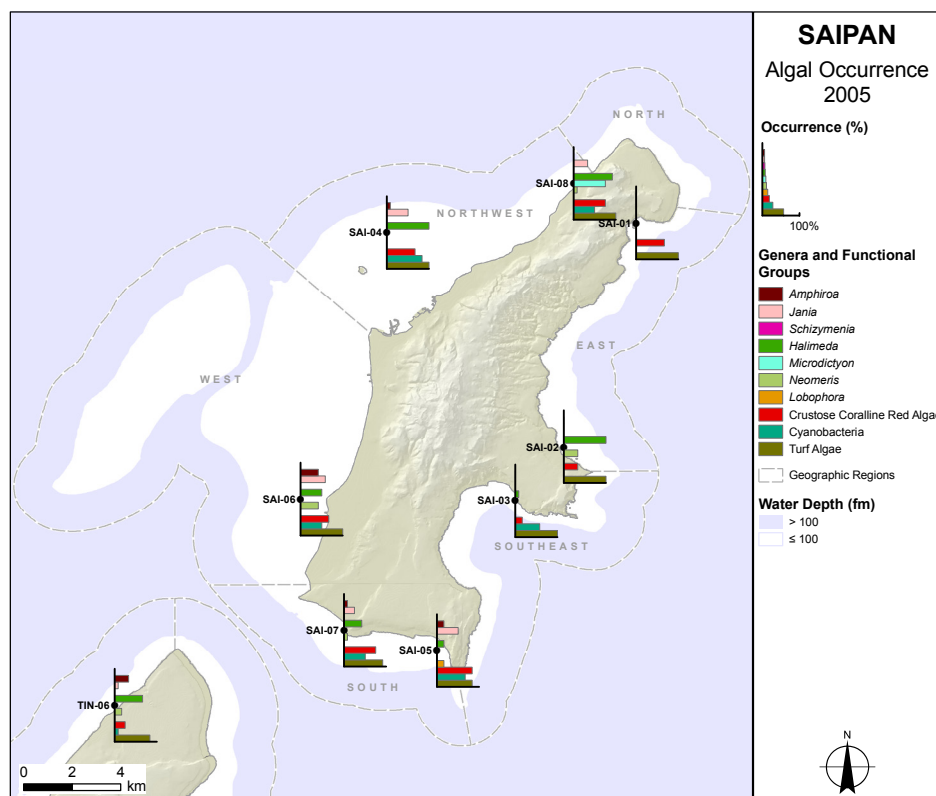
**Figure 8.6.1d.** Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats conducted at Saipan during MARAMP 2003. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

During MARAMP 2005, REA benthic surveys were conducted at 8 sites on forereef habitats around Saipan. In the field, 23 macroalgal genera (9 red, 10 green, and 4 brown), containing at least 23 species, as well as 4 additional algal functional groups—turf algae, crustose coralline red algae, branched, nongeniculate coralline red algae, and cyanophytes—were observed. SAI-02 in the east region had the highest macroalgal generic diversity with 13 genera, containing 13 species, documented in the field. The lowest macroalgal generic diversity was found at SAI-01 in the east region and SAI-03 in the southeast region with 3 species representing 3 genera recorded.

Species of *Halimeda*, the red alga *Jania*, and the brown alga *Dictyota* were all relatively abundant around Saipan in 2005 (Fig. 8.6.1e), occurring in 51%, 27%, and 19% of sampled photoquadrats. Species of the red algae *Amansia*, *Actinotrichia*, *Amphiroa*, and *Galaxaura* and the green alga *Caulerpa* were less abundant around this island, occurring in 8%–11% of sampled photoquadrats. However, in many cases, these genera were found in much greater abundance at a single REA site. None of the genera identified during MARAMP 2005 were observed at all 8 sites surveyed around Saipan. Species of *Halimeda* were recorded at 7 of the 8 REA survey sites (they were absent at SAI-01 in Bahia Fanonchuluyan), occurring in 8% of sampled photoquadrats at SAI-03 in the southeast region and in 100% of sampled photoquadrats at both SAI-02 in the east region near Puntan Halaihai and SAI-04 in the west region. The sites with low *Halimeda* abundance—SAI-01, SAI-03, SAI-05—were all protected from a northeast exposure, and this protection may help explain patterns in the distribution of this genus around Saipan. Species of the calcified alga *Jania* were recorded at 4 of the 8 REA sites, occurring in 25%–58% of sampled photoquadrats, at SAI-04, SAI-06, SAI-07, SAI-08 but were absent in the east and southeast regions.

Turf algae, crustose coralline red algae, and cyanobacteria were all exceptionally common in 2005, occurring in 97%, 60%, and 45% of sampled photoquadrats around Saipan. Communities of both turf algae and crustose coralline red algae were prevalent at all sites. Turf algae occurred in 83%–100% of sampled photoquadrats, and crustose coralline red algae, with more varied abundance, was found in 16%–83% of sampled photoquadrats (Fig. 8.6.1e). Although cyanobacteria were not documented at SAI-01 or SAI-02, they occurred in 50%–83% of photoquadrats sampled at all other sites.

**Figure 8.6.1e.** Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats conducted around Saipan during MARAMP 2005. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

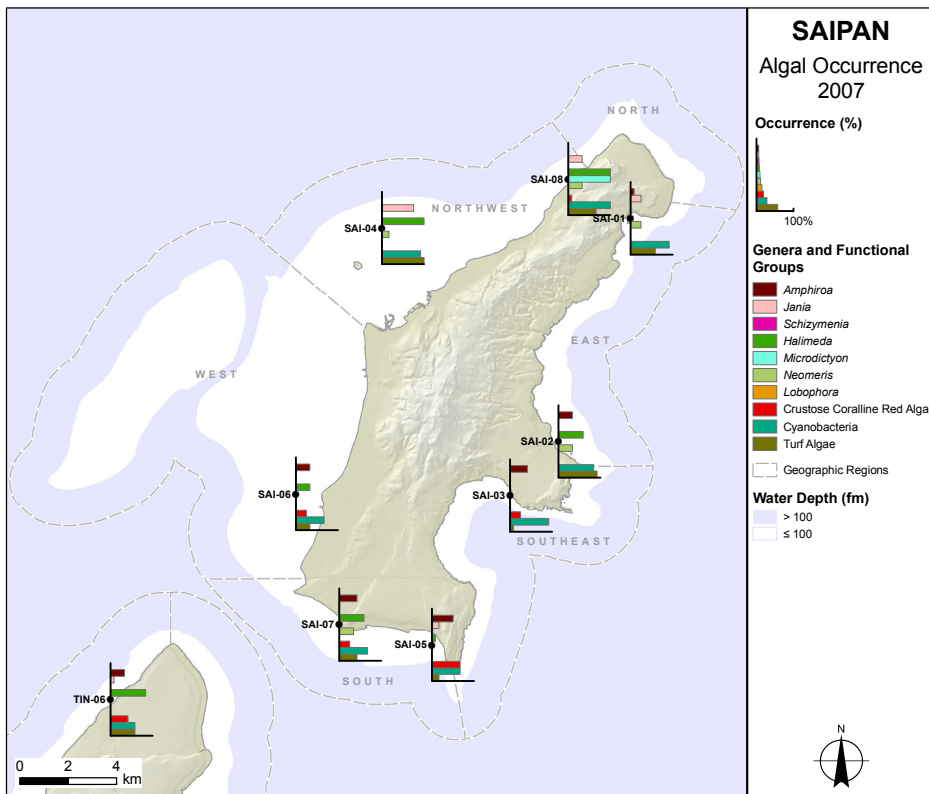


During MARAMP 2007, REA benthic surveys were conducted at 8 sites on forereef habitats around Saipan. In the field, 26 macroalgal genera (14 red, 10 green, and 2 brown), containing at least 46 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. SAI-02 near Halaihai in the east region had the highest macroalgal generic diversity with 13 genera, containing 17 species, documented in the field. SAI-03 in the southeast region and SAI-05 in the south region had the lowest macroalgal generic diversity with 4 species representing 4 genera recorded.

Species of *Halimeda* were the most common components of the algal communities around Saipan in 2007 (Fig. 8.6.1f), occurring in 45% of photoquadrats sampled. Species of the red algae *Tolypocladia* and *Amphiroa* were also moderately abundant, both occurring in 26% of the photoquadrats sampled at Saipan; however, these 2 genera were mutually exclusive at every site. Species of *Tolypocladia* occurred only at sites on the northern half of Saipan (SAI-01: 33%; SAI-02: 75%; SAI-04: 92%; SAI-08: 8%), while species of *Amphiroa* occurred only in habitats surrounding the southern half of the island (SAI-02: 33%; SAI-03: 42%; SAI-05: 50%; SAI-06: 33%; SAI-07: 42%). Species of *Neomeris*, *Microdictyon*, and *Padina* occurred in 18%, 12.5%, and 17% of sampled photoquadrats. Although some genera occurred in relatively high abundance, none were recorded at all sites.

Cyanobacteria and turf algae were ubiquitous at every site in 2007, occurring in 82% and 52% of photoquadrats sampled around Saipan. Turf algae were observed in 7%–100% of sampled photoquadrats, whereas cyanobacteria were found in 67%–100% of sampled photoquadrats (Fig. 8.6.1f). Crustose coralline red algae were recorded in 19% of sampled photoquadrats around the island but were absent from both sites in the east region, SAI-01 Bahia Fanonchuluyan and SAI-02 near Puntan Halaihai, and from SAI-04 in the northwest region.

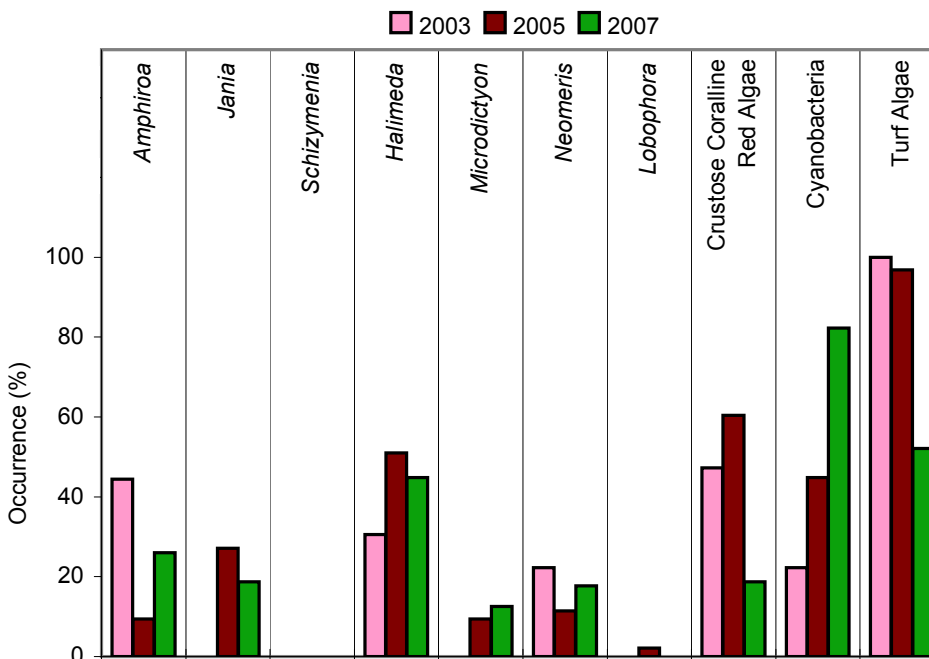
The number of macroalgal genera recorded on forereef habitats at Saipan increased from 13 to 23 genera between MARAMP 2003 and 2005—and rose by 3 genera to 26 in 2007. Species diversity also increased between MARAMP 2003 and 2007 with 16, 23, and 46 species recorded in 2003, 2005, and 2007. Five additional sites were surveyed in 2005 and 2007 beyond the 3 sites surveyed in 2003. This greater survey effort likely accounts for some of the increase in the number of observed genera from 2003 to 2007 (for information on data limitations, see Chapter 2: “Methods and Operational Background, Section 2.4: “Reef Surveys”). Species of *Halimeda* consistently exhibited high values of occurrence during the 3 survey years with an average occurrence range of 30.1%–51%; however, no patterns in occurrence were detected (Fig. 8.6.1g). Species of *Amphiroa* also were observed in relatively high abundance in 2003 and 2007, occurring in 44%



**Figure 8.6.1f.** Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats conducted around Saipan during MARAMP 2007. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of x-axis denotes 100% occurrence.

and 26% of sampled photoquadrats; however, no individuals were recorded in 2005. Other common genera were *Jania*, *Dictyota*, *Tricleocarpa*, *Neomeris*, and *Tolypocladia*.

The occurrence of crustose coralline red algae on forereef habitats at Saipan differed greatly between MARAMP survey years but with no clear pattern, increasing from 47% in 2003 to 60% in 2005 and decreasing to 18% in 2007. Turf-algal occurrence at Saipan declined slightly from 100% in 2003 to 97% in 2005 and continued to decrease in 2007 to 52%. Occurrence values of cyanobacteria climbed from 22% in 2003 to 45% in 2005 then jumped to 82% in 2007.

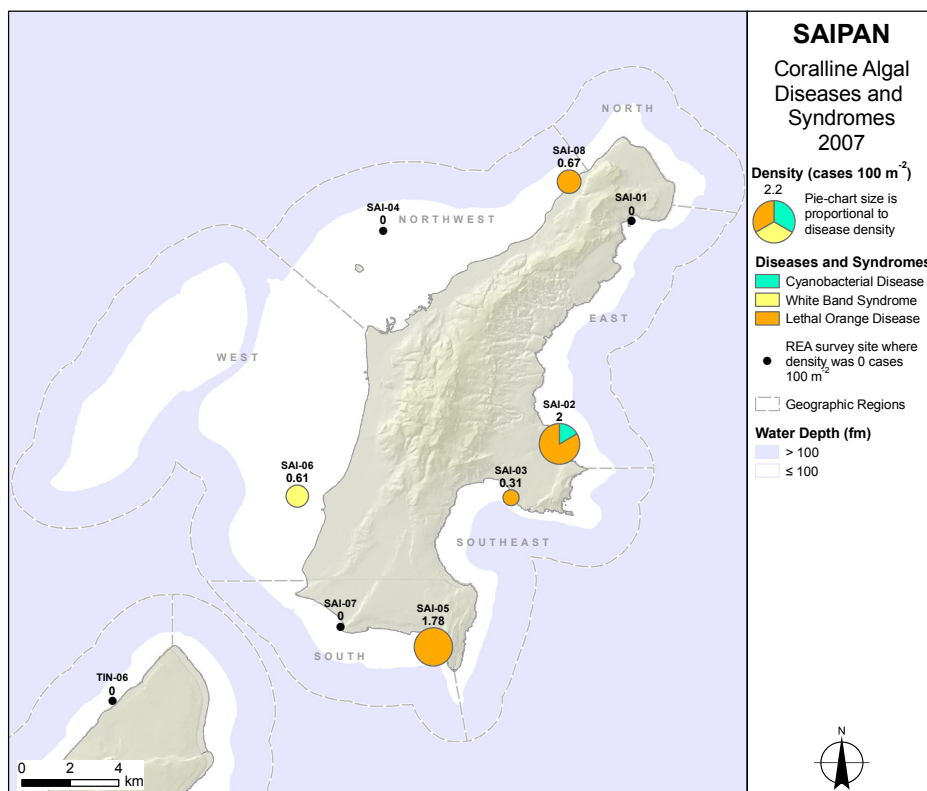


**Figure 8.6.1g.** Temporal comparison of occurrence (%) values from REA benthic surveys of algal genera and functional groups conducted on forereef habitats at Saipan during MARAMP 2003, 2005, and 2007.

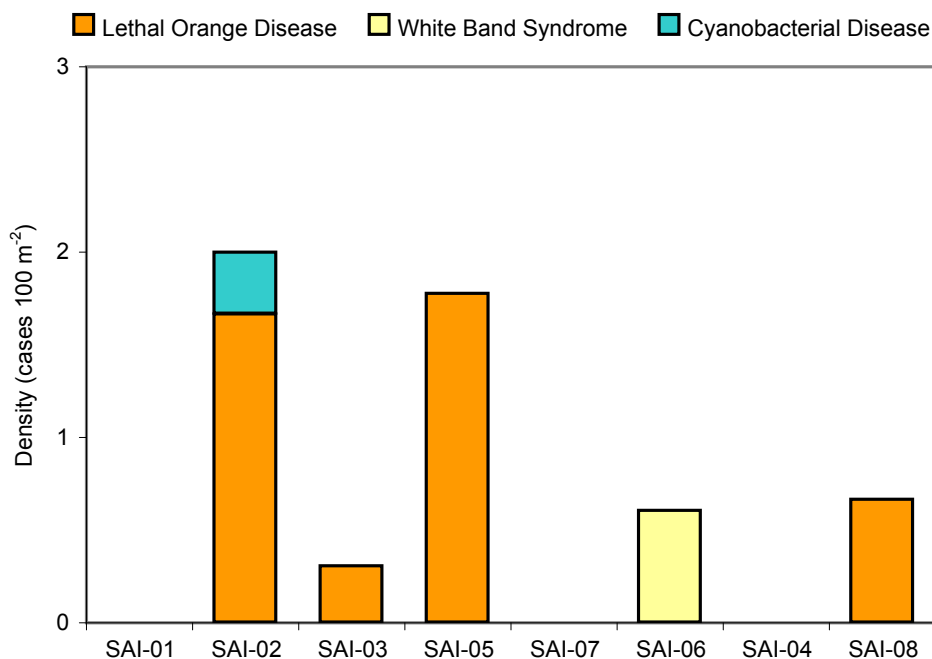
## 8.6.2 Surveys for Coralline Algal Disease

During MARAMP 2007, REA benthic surveys for coralline-algal disease were conducted in concert with coral-disease assessments at 8 sites on foreereef habitats around Saipan, covering a total reef area of more than 2200 m<sup>2</sup>. Disease of coralline algae was found at 5 sites with a mean overall density of 0.67 cases 100 m<sup>-2</sup> (SE 0.28). The highest density value of 2 cases 100 m<sup>-2</sup> was recorded at SAI-02 near Puntan Halaihai in the east region (Figs. 8.6.2a and b). Three major types of diseases were registered around Saipan: coralline lethal orange disease, coralline white band syndrome, and a coralline cyanobacterial disease. Coralline lethal orange disease was the most numerous disease around Saipan, representing 86% of all cases islandwide. Only 1 case each of cyanobacterial disease, at SAI-02 in the east region, and white band syndrome, at SAI-06 in the west region, were detected.

**Figure 8.6.2a.** Densities (cases 100 m<sup>-2</sup>) of coralline-algal diseases from REA benthic surveys conducted on foreereef habitats around Saipan during MARAMP 2007. The color-coded portions of the pie charts indicate disease-specific density.



**Figure 8.6.2b.** Densities (cases 100 m<sup>-2</sup>) of the coralline-algal diseases from REA benthic surveys conducted on foreereef habitats around Saipan during MARAMP 2007.





## 8.7 Benthic Macroinvertebrates

### 8.7.1 Benthic Macroinvertebrates Surveys

Four groups of benthic macroinvertebrates—sea urchins, sea cucumbers, giant clams, and crown-of-thorns seastars (COTS)—were monitored on forereef habitats around the island of Saipan through REA and towed-diver benthic surveys during MARAMP 2003, 2005, and 2007. This section describes by group the results of these surveys. A list of additional taxa observed during REA invertebrate surveys are provided in Chapter 3: “Archipelagic Comparisons”.

Monitoring these 4 groups of ecologically and economically important taxa provides insight into the population distribution, community structure, and habitats of the coral reef ecosystems of the Mariana Archipelago. High densities of the corallivorous COTS can affect greatly the community structure of reef ecosystems. Giant clams are filter feeders that are sought after in the Indo-Pacific for their meat, which is considered a delicacy, and for their shells. Sea cucumbers, sand-producing detritus foragers, are harvested for food. Sea urchins are important algal grazers and bioeroders.

In 2003, 3 REA surveys and 6 towed-diver benthic surveys were conducted, and in 2005, 8 REA surveys and 17 towed-diver benthic surveys were performed around Saipan. In 2007, because of the lack of a scientific diver with expertise in invertebrates, no REA surveys were conducted; however, 16 towed-diver benthic surveys were completed. Also, when considering survey results from towed-diver surveys, keep in mind that cryptic or small organisms can be difficult for divers to see, so the density values presented in this report, especially of giant clams and sea urchins, may under-represent the number of individuals present.

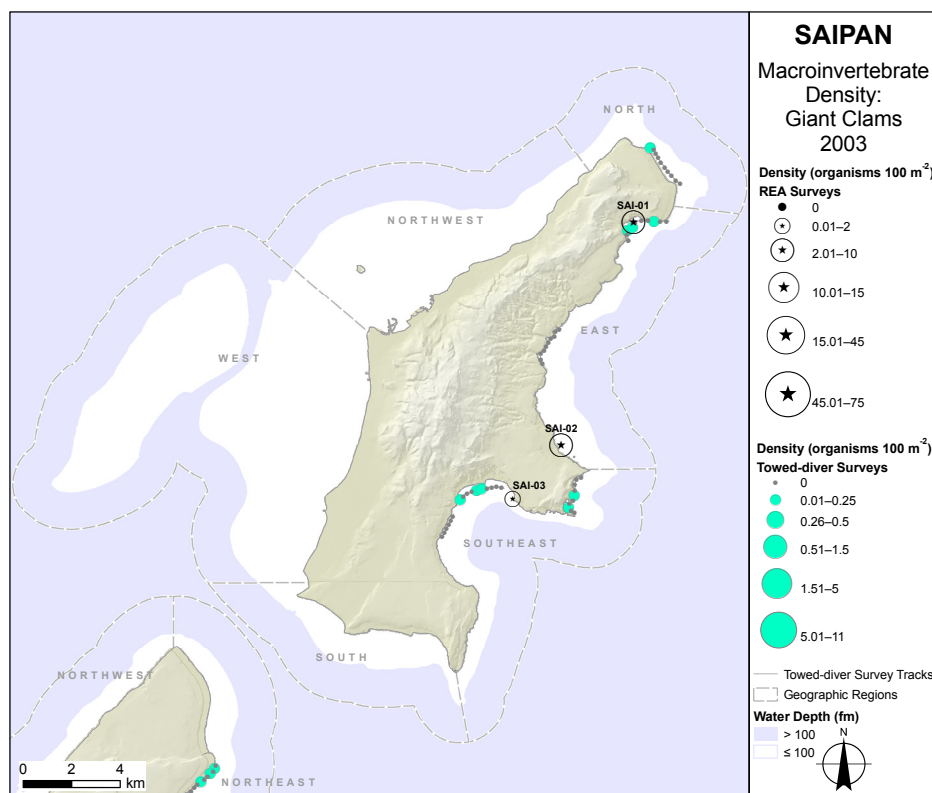
Overall, towed-diver surveys suggested low daytime macroinvertebrate abundance on forereef habitats around Saipan compared to the rest of the Mariana Archipelago. Minor fluctuations in observed densities between MARAMP survey periods occurred with all target groups. Temporal patterns of islandwide mean macroinvertebrate density around Saipan—from towed-diver benthic surveys during MARAMP 2003, 2005, and 2007—are shown later in this section (Figs. 8.7.1d, h, l, and p). Because of the variable REA survey effort, with 3 surveys in 2003, 6 in 2005, and no surveys in 2007, temporal comparisons of REA data are not presented (see Chapter 2: “Methods and Operational Background, Section 2.4.7: “Benthic Macroinvertebrates”).

#### **Giant Clams**

During MARAMP 2003, species of *Tridacna* giant clams were observed at all 3 REA sites and in 5 of the 6 towed-diver surveys conducted at Saipan (Fig. 8.7.1a). Surveys in 2003 were conducted only in the east, southeast, and north regions. The sample mean density of giant clams from REA surveys was 2.86 organisms 100 m<sup>-2</sup> (SE 0.46), and the overall mean density from towed-diver surveys was 0.009 organisms 100 m<sup>-2</sup> (SE 0.004). Survey results suggest giant clams were most abundant at REA site SAI-01 in Bahia Fanonchuluyan in the east region with 3.57 organisms 100 m<sup>-2</sup> (for place-names and their locations, see Fig. 8.2a in Section 8.2: “Survey Effort”). Among the towed-diver surveys at Saipan, all of which were conducted in the north, east, or southeast regions, the survey completed between Puntans Laolao Kattan and Hakmang in the southeast region had the highest mean density of giant clams with 0.022 organisms 100 m<sup>-2</sup>; segment densities from on this survey ranged from 0 to 0.173 organisms 100 m<sup>-2</sup>. The second-greatest mean density of giant clams from a towed-diver survey was 0.015 organisms 100 m<sup>-2</sup>, recorded along the shoreline north of Tuturam; segment densities ranged from 0 to 0.056 organisms 100 m<sup>-2</sup>.

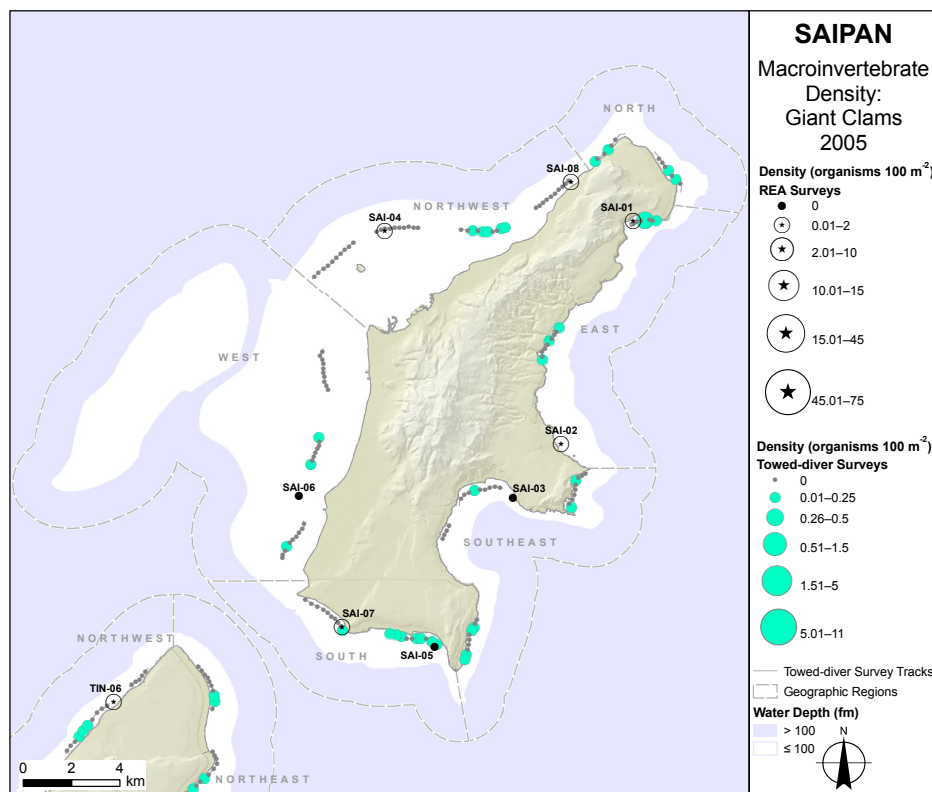
During MARAMP 2005, giant clams were observed at 5 of the 8 REA sites and in 12 of the 17 towed-diver surveys conducted around Saipan (Fig. 8.7.1b). The overall mean density of giant clams from REA surveys was 1 organism 100 m<sup>-2</sup> (SE 0.33), and the islandwide mean density from towed-diver surveys was 0.018 organisms 100 m<sup>-2</sup> (SE 0.003). Survey results suggest giant clams were most abundant at SAI-02 in Bahia Fanonchuluyan in the east region, SAI-04 north of Isleta Managaha in the northwest region, and SAI-07 near Puntan Opyan in the south region, each with 2 organisms 100 m<sup>-2</sup>. Among all towed-diver surveys around this island, the survey completed in Bahia Fanonchuluyan had the highest mean density of giant clams with 0.05 organisms 100 m<sup>-2</sup>; segment densities from this survey ranged from 0 to 0.294 organisms 100 m<sup>-2</sup>. The second-greatest mean density of giant clams from a towed-diver survey was 0.048 organisms 100 m<sup>-2</sup>, recorded in the northwest region near Puntan Achugao; segment densities ranged from 0 to 0.16 organisms 100 m<sup>-2</sup>.

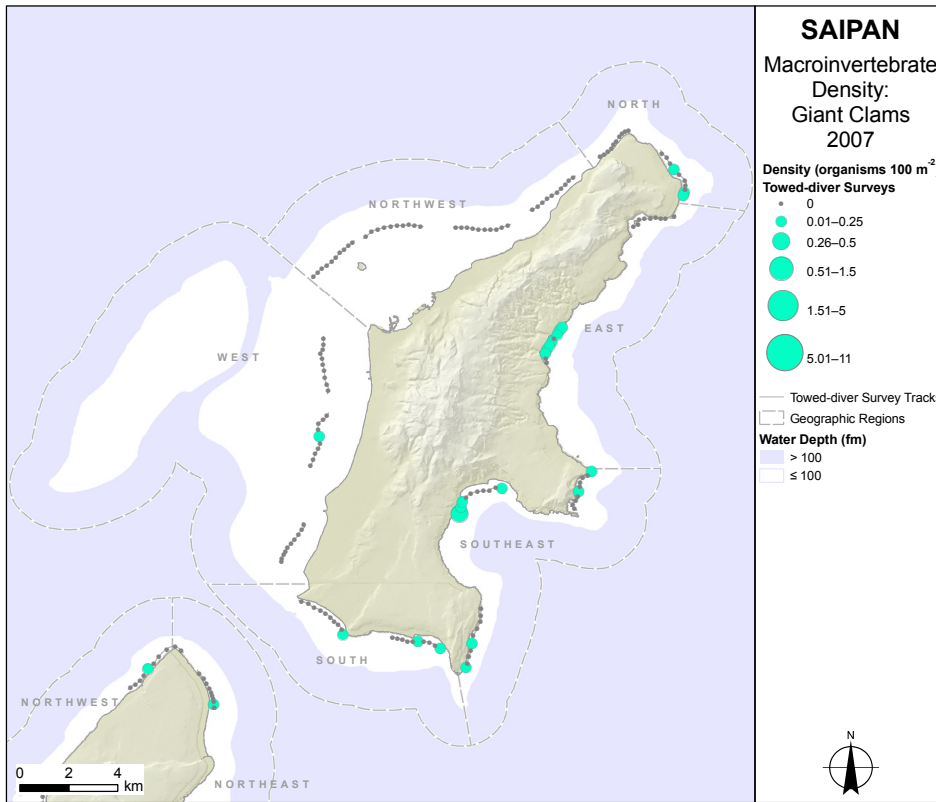
**Figure 8.7.1a.** Densities (organisms 100 m<sup>-2</sup>) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted at Saipan during MARAMP 2003.



During MARAMP 2007, giant clams were observed in 8 of the 16 towed-diver surveys conducted around Saipan (Fig. 8.7.1c) with an islandwide mean density of 0.012 organisms 100 m<sup>-2</sup> (SE 0.003). Among all towed-diver surveys around this island, the survey completed along Talof<sup>o</sup>fo<sup>o</sup>, Unai in the east region had the highest mean density of giant clams with 0.063 organisms 100 m<sup>-2</sup>; segment densities from this survey ranged from 0 to 0.16 organisms 100 m<sup>-2</sup>. The second-greatest mean density of giant clams from a towed-diver survey was 0.046 organisms 100 m<sup>-2</sup>, recorded north of Tuturam in Bahia Laolao in the southeast region; segment densities ranged from 0 and 0.253 organisms 100 m<sup>-2</sup>.

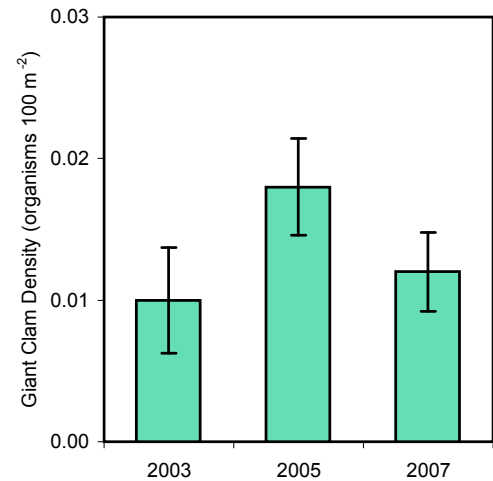
**Figure 8.7.1b.** Densities (organisms 100 m<sup>-2</sup>) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted around Saipan during MARAMP 2005.





**Figure 8.7.1c.** Densities (organisms 100 m<sup>-2</sup>) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted around Saipan during MARAMP 2007.

Towed-diver surveys suggested low abundance of giant clams around Saipan during MARAMP survey periods, relative to the rest of the Mariana Archipelago (Fig. 8.7.1d). Minor fluctuations in density were observed, but this variation is not necessarily indicative of changes in the population structure of giant clams (For information about data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”).

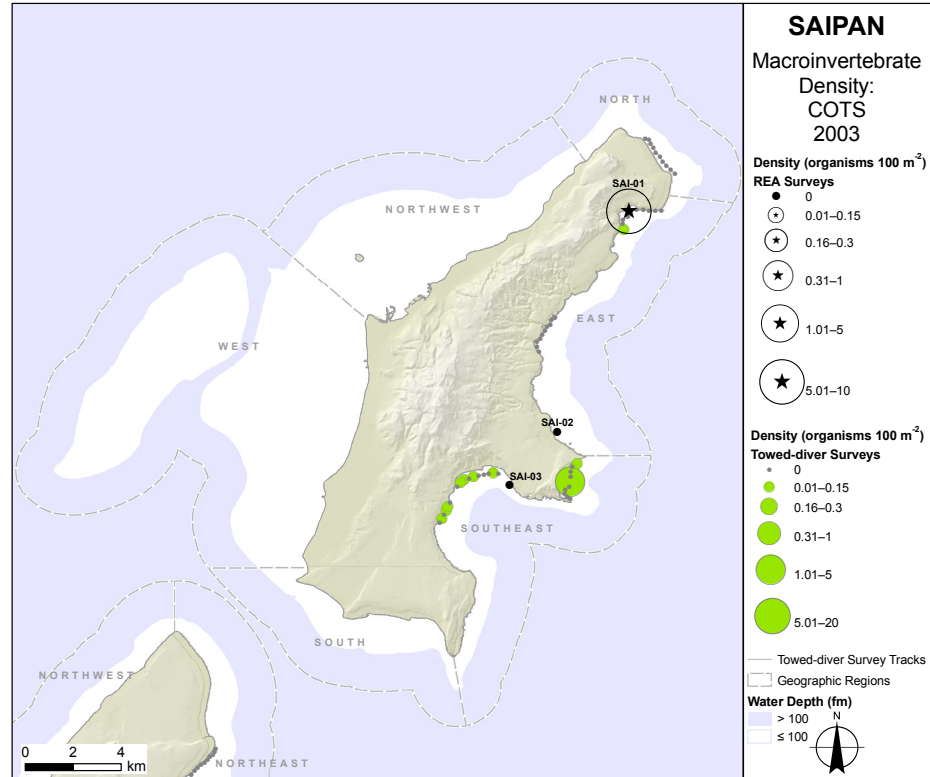


**Figure 8.7.1d.** Temporal comparison of mean densities (organisms 100 m<sup>-2</sup>) of giant clams from towed-diver benthic surveys conducted on forereef habitats around Saipan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error ( $\pm 1$  SE) of the mean.

## Crown-of-thorns Seastars

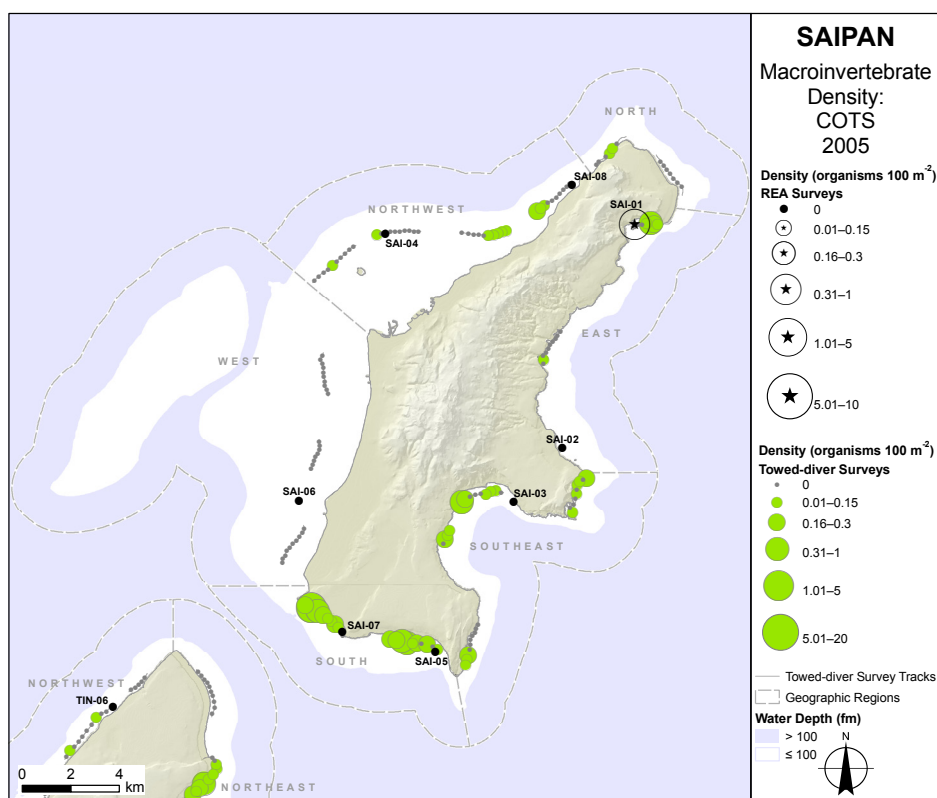
During MARAMP 2003, crown-of-thorns seastars (*Acanthaster planci*) were observed at 1 of the 3 REA sites surveyed and in 4 of the 6 towed-diver surveys conducted at Saipan (Fig. 8.7.1e). SAI-01 in Bahia Fanonchuluyan in the east region had a COTS density of 7.14 organisms 100 m<sup>-2</sup>. The overall mean density of COTS from towed-diver surveys was 0.045 organisms 100 m<sup>-2</sup> (SE 0.035). Among the towed-diver surveys at Saipan, all of which were conducted in the north, east, or southeast regions, the survey completed between Puntans Laolao Kattan and Hakmang in the southeast region had the highest mean density of COTS with 0.199 organisms 100 m<sup>-2</sup>; segment densities from this survey ranged from 0 to 1.95 organisms 100 m<sup>-2</sup>. The second-greatest mean density of COTS from a towed-diver survey was 0.04 organisms 100 m<sup>-2</sup>, recorded north of Taturam in Bahia Laolao in the southeast region; segment densities ranged from 0 to 0.143 organisms 100 m<sup>-2</sup>.

**Figure 8.7.1e.** Densities (organisms 100 m<sup>-2</sup>) of COTS from REA and towed-diver benthic surveys of forereef habitats conducted at Saipan during MARAMP 2003.

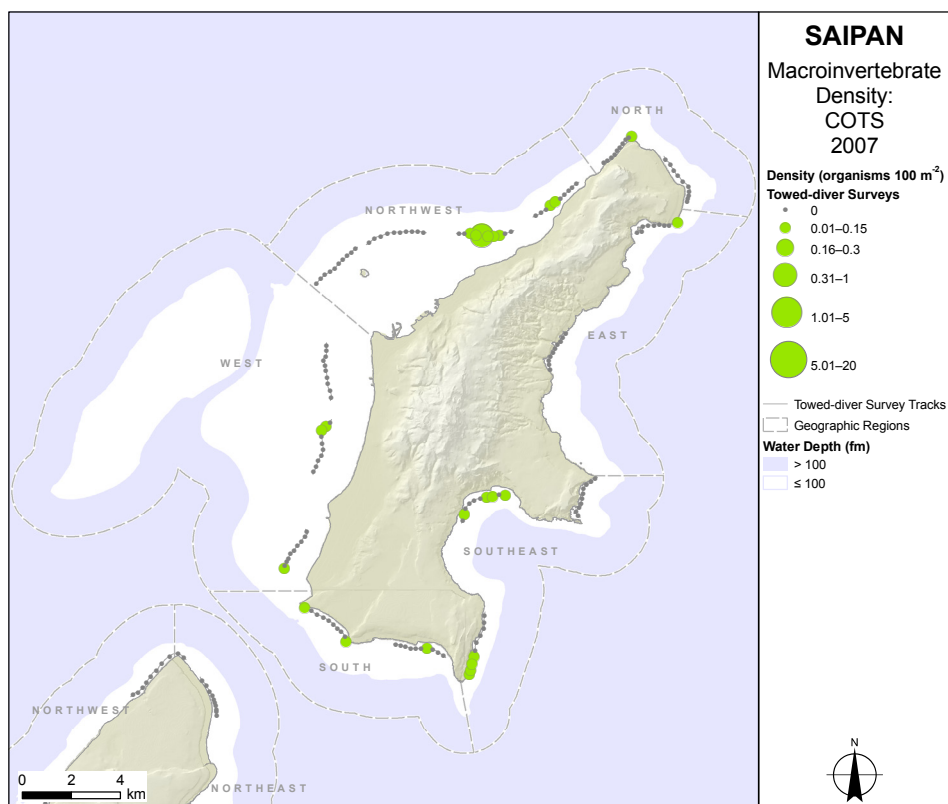


During MARAMP 2005, COTS were observed at 1 of the 8 REA sites surveyed and in 13 of the 17 towed-diver surveys conducted around Saipan (Fig. 8.7.1f). SAI-01 in the east region had a COTS density of 1 organism 100 m<sup>-2</sup>. The island-wide mean density of COTS from towed-diver surveys was 0.062 organisms 100 m<sup>-2</sup> (SE 0.017). The majority of COTS recorded during towed-diver surveys were observed in the south region. Among all towed-diver surveys around this island, the survey completed between Puntans Opyan and Agingan in the south region had the highest mean density of COTS with 0.35 organisms 100 m<sup>-2</sup>; segment densities from this survey ranged from 0 to 2.25 organisms 100 m<sup>-2</sup>. The second-greatest mean density of COTS from a towed-diver survey was 0.24 organisms 100 m<sup>-2</sup>, recorded between Puntans Unai Opyan and Opyan; segment densities ranged from 0 to 0.7 organisms 100 m<sup>-2</sup>. The third-greatest mean density was 0.112 organisms 100 m<sup>-2</sup>, recorded in the east region in Bahia Fanonchuluyan; segment densities ranged from 0 to 0.324 organisms 100 m<sup>-2</sup>.

During MARAMP 2007, COTS were observed in 10 of the 16 towed-diver surveys conducted around Saipan (Fig. 8.7.1g) with an islandwide mean density of 0.012 organisms 100 m<sup>-2</sup> (SE 0.003). Among all towed-diver surveys around this island, the survey completed in the northwest region near Puntan Achugao had the highest mean density of COTS with 0.09 organisms 100 m<sup>-2</sup>; segment densities from this survey ranged from 0 to 0.42 organisms 100 m<sup>-2</sup>.

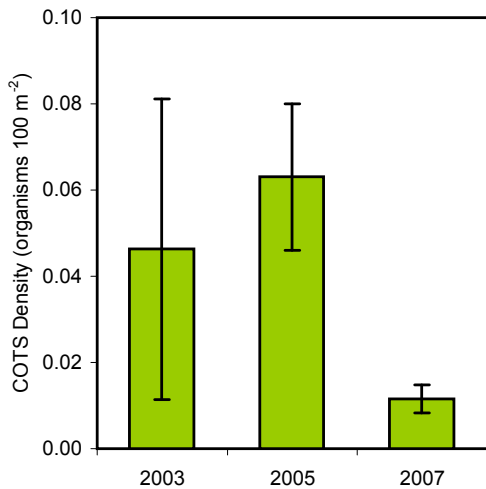


**Figure 8.7.1f.** Densities (organisms 100 m<sup>2</sup>) of COTS from REA and towed-diver benthic surveys of forereef habitats conducted around Saipan during MARAMP 2005.



**Figure 8.7.1g.** Densities (organisms 100 m<sup>2</sup>) of COTS from REA and towed-diver benthic surveys of forereef habitats conducted around Saipan during MARAMP 2007.





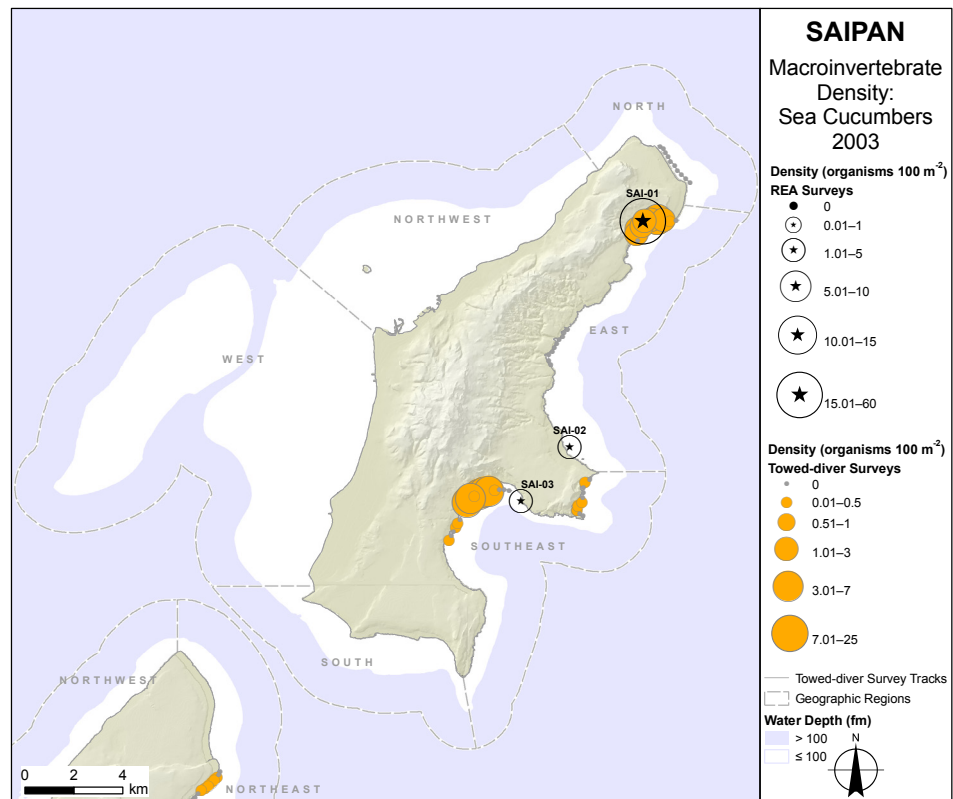
**Figure 8.7.1h.** Temporal comparison of COTS mean densities (organisms 100 m<sup>-2</sup>) from towed-diver benthic surveys conducted on forereef habitats around Saipan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error ( $\pm 1$  SE) of the mean.

During MARAMP 2003 and 2005, individual towed-diver surveys suggested high daytime densities of COTS in localized areas around Saipan, compared to other areas surveyed around Saipan. However, densities from surveys conducted in 2007 were down from values recorded in previous survey years (Fig. 8.7.1h), suggesting a sharp decline in COTS population. Given that these corallivorous seastars can decimate a reef, understanding whether their observed densities signify an outbreak is important. By means of a manta-tow technique—which uses snorkel divers as observers in a manner similar to the procedure established for using scuba divers to conduct MARAMP towed-diver surveys—Moran and De’ath (1992) defined a potential outbreak as a reef area where the density of *A. planci* was  $> 1500$  organisms km<sup>-2</sup> (0.15 organisms 100 m<sup>-2</sup>) and the level of dead coral present was at least 40%. Using this definition only in terms of density and considering each towed-diver survey as an individual reef area, localized areas with relatively high densities that suggest that they were undergoing an outbreak were found during MARAMP 2003 and 2005. In 2003, such areas were observed during a towed-diver survey between Puntans Laolao Kattan and Hakmang in the southeast region with 0.199 organisms 100 m<sup>-2</sup>. In 2005, the aforementioned density criterion was met in 2 towed-diver surveys in the south region between Puntans Unai Opyan and Agingan with 0.35 and 0.24 organisms 100 m<sup>-2</sup>. COTS density naturally fluctuates with food availability and variation in recruitment success (Birkeland and Lucas 1990; Fabricius et al. 2010; and Yamaguchi 1987).

### Sea Cucumbers

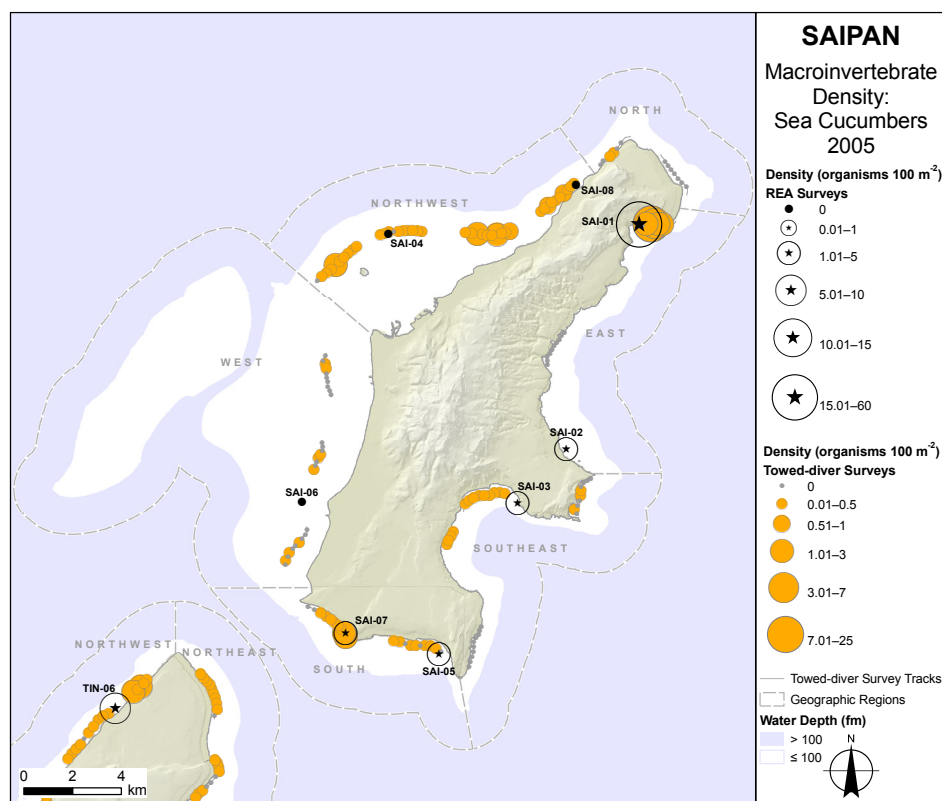
During MARAMP 2003, sea cucumbers were observed at all 3 REA sites surveyed and in 4 of the 6 towed-diver surveys conducted at Saipan (Fig. 8.7.1i). The sample mean density from REA surveys was 15.43 organisms 100 m<sup>-2</sup> (SE 11.96),

**Figure 8.7.1i.** Density (organisms 100 m<sup>-2</sup>) of sea cucumbers from REA and towed-diver benthic surveys conducted of forereef habitats at Saipan during MARAMP 2003.



and the overall mean density from towed-diver surveys was 0.568 organisms 100 m<sup>-2</sup> (SE 0.161). Survey results suggest sea cucumbers were most abundant at SAI-01 with 11 organisms 100 m<sup>-2</sup> and with 91% of these observations containing species within the genus *Stichopus*. The other recorded genus was *Holothuria*. Among the towed-diver surveys at Saipan, all of which were conducted in the north, east, or southeast regions, the survey completed north of Tutturam in Bahia Laolao in the southeast region had the highest mean density of sea cucumbers with 1.9 organisms 100 m<sup>-2</sup>; segment densities from this survey ranged from 0 to 4.183 organisms 100 m<sup>-2</sup>. The second-greatest mean density of sea cucumbers was 1.39 organisms 100 m<sup>-2</sup>, recorded in Bahia Fanonchuluyan in the east region; segment densities ranged from 0 to 3.059 organisms 100 m<sup>-2</sup>.

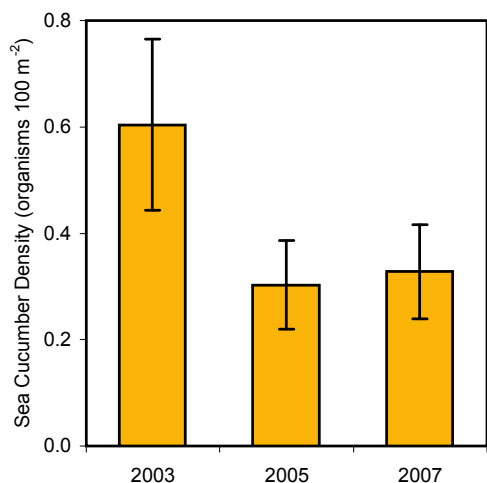
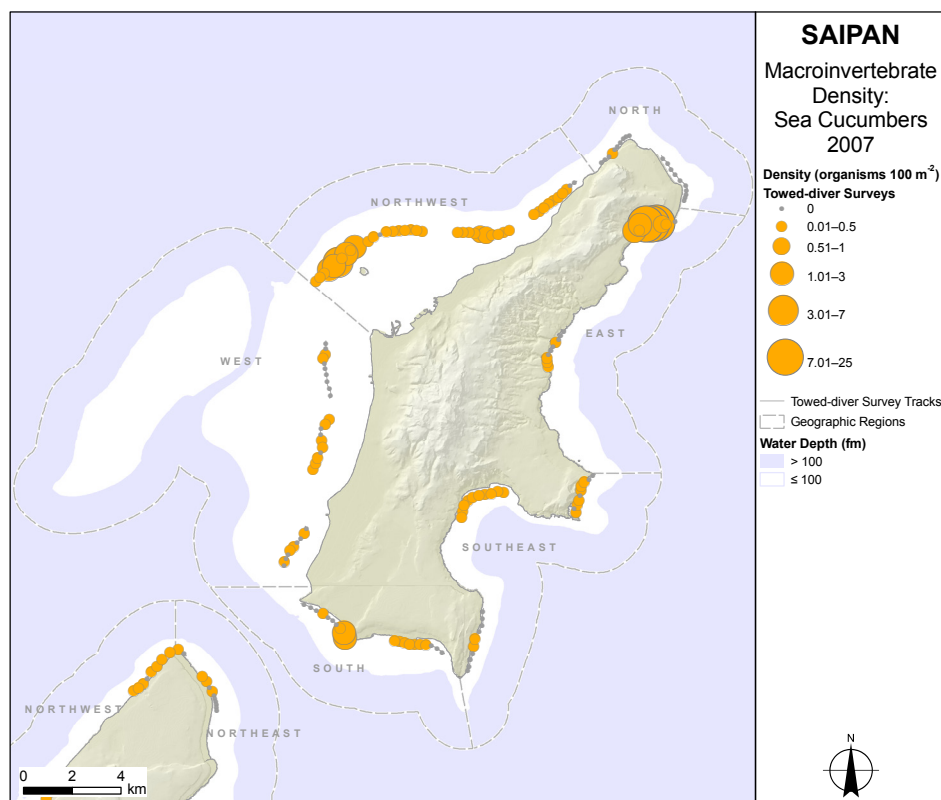
During MARAMP 2005, sea cucumbers were observed at 5 of the 8 REA sites surveyed and in 15 of the 17 towed-diver surveys conducted around Saipan (Fig. 8.7.1j). The overall mean density of sea cucumbers from REA surveys was 5.37 organisms 100 m<sup>-2</sup> (SE 3.57), and the islandwide mean density from towed-diver surveys was 0.34 organisms 100 m<sup>-2</sup> (SE 0.08). Survey results suggest sea cucumbers were most abundant at SAI-01 with 30 organisms 100 m<sup>-2</sup>; all of them came from the genus *Stichopus*. In 2005, 91% of all sea cucumbers recorded were from the genus *Stichopus*; the only other representative genus was *Holothuria*. Among all towed-diver surveys around this island, the survey completed in Bahia Fanonchuluyan in the east region had the highest mean density of sea cucumbers with 3.21 organisms 100 m<sup>-2</sup>; segment densities from this survey ranged from 0 to 10.3 organisms 100 m<sup>-2</sup>. The second-greatest mean density of sea cucumbers from a towed-diver survey was 0.63 organisms 100 m<sup>-2</sup>, recorded in the northwest region near Puntan Achugao; segment densities ranged from 0 to 1.91 organisms 100 m<sup>-2</sup>.



**Figure 8.7.1j.** Densities (organisms 100 m<sup>-2</sup>) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted around Saipan during MARAMP 2005.

During MARAMP 2007, sea cucumbers were observed in 15 of the 16 towed-diver benthic surveys conducted around Saipan (Fig. 8.7.1k) with an islandwide mean density of 3.45 organisms 100 m<sup>-2</sup> (SE 0.09). Among all towed-diver surveys around Saipan, the survey completed in Bahia Fanonchuluyan in the east region had the highest mean density of sea cucumbers with 3.07 organisms 100 m<sup>-2</sup>; segment densities from this survey ranged from 0 to 7.77 organisms 100 m<sup>-2</sup>. The second-greatest mean density of sea cucumbers from a towed-diver survey was 1.11 organisms 100 m<sup>-2</sup>, recorded just west of Isleta Managaha in the northwest region; segment densities ranged from 0.02 to 3.3 organisms 100 m<sup>-2</sup>.

**Figure 8.7.1k.** Densities (organisms 100 m<sup>-2</sup>) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted around Saipan during MARAMP 2007.



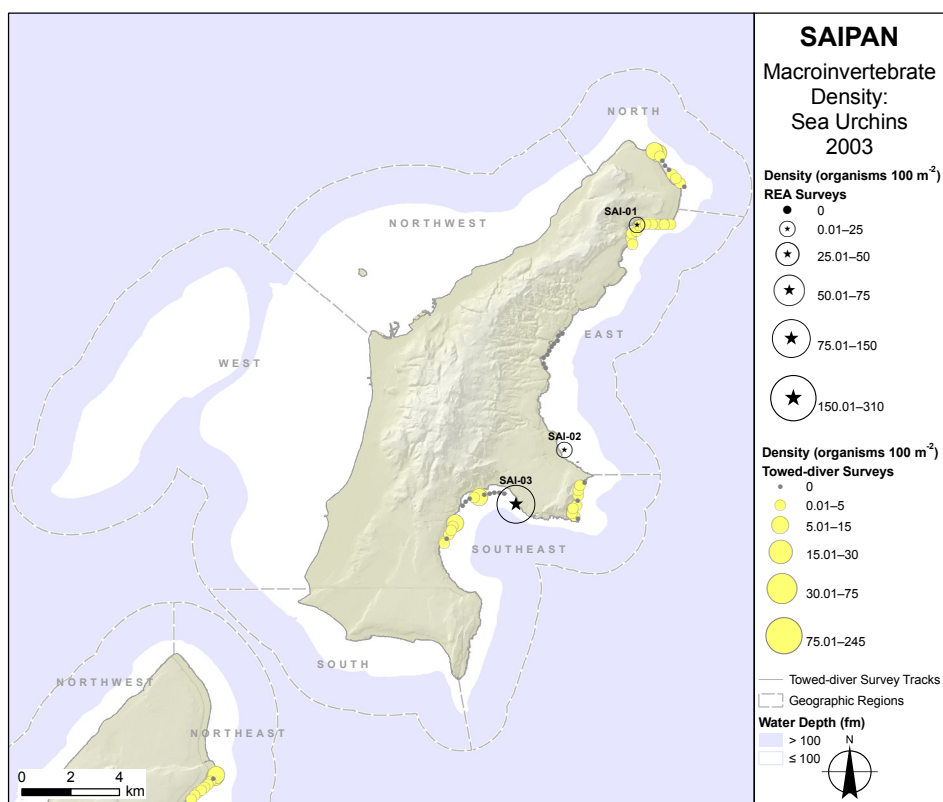
**Figure 8.7.1l.** Temporal comparison of mean densities (organisms 100 m<sup>-2</sup>) of sea cucumbers from towed-diver benthic surveys conducted on forereef habitats around Saipan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error ( $\pm 1$  SE) of the mean.

Towed-diver and REA surveys across the 3 MARAMP survey years suggested low daytime abundance of sea cucumbers around Saipan, relative to the rest of the Mariana Archipelago, with the exception of surveys conducted in the east region in Bahia Fanonchuluyan, where densities of sea cucumbers were higher than anywhere else around this island. The overall observed mean density of sea cucumbers from towed-diver surveys was lower in 2005 and 2007 than in 2003 (Fig. 8.7.1l). Minor fluctuations in densities are not necessarily indicative of changes in the population structure of sea cucumbers (For information about data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”).

## Sea Urchins

During MARAMP 2003, sea urchins were observed at both REA sites surveyed and in 5 of the 6 towed-diver surveys conducted at Saipan (Fig. 8.7.1m). The sample mean density of sea urchins from REA surveys was 49.33 organisms 100 m<sup>-2</sup> (SE 28.9), and the overall mean density from towed-diver surveys was 1.37 organisms 100 m<sup>-2</sup> (SE 0.33). Survey results suggest sea urchins were most abundant at SAI-03, located between Puntans Hakmang and Tuturam in the southeast region, with 107 organisms 100 m<sup>-2</sup>. At this site, 61% of sea urchins were of the genus *Diadema*, 28% were rock-boring urchins in the genus *Echinostrephus*, and 11% were of the genus *Echinothrix*. SAI-02 had the second-greatest density of sea urchins with 16 organisms 100 m<sup>-2</sup>. Three genera were recorded at this site: *Echinostrephus*, *Echinometra*, and *Echinothrix*. The rock-boring urchin *Echinostrephus* accounted for 87.5% of sea urchins recorded.

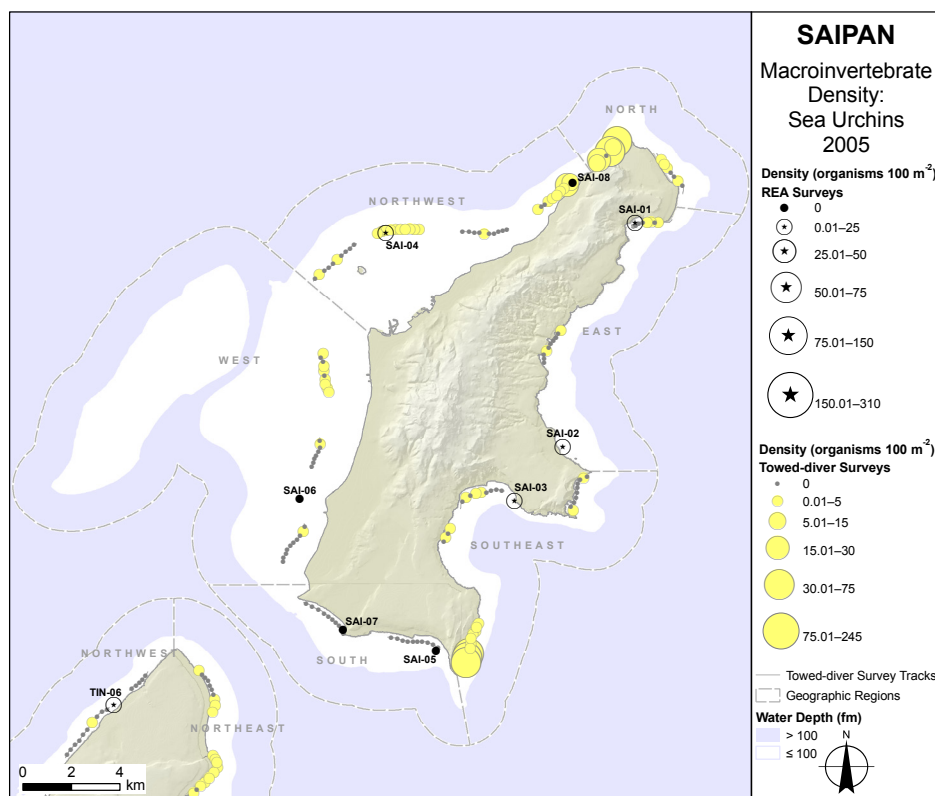
Among the towed-diver surveys conducted at Saipan in 2003, all of which were conducted in the north, east, or southeast regions, the survey completed south of Tuturam in the southeast region had the highest mean density of sea urchins with 2.81 organisms 100 m<sup>-2</sup>; segment densities from this survey ranged from 0 to 7.19 organisms 100 m<sup>-2</sup>. The second-greatest mean density of sea urchins was 2.54 organisms 100 m<sup>-2</sup>, recorded in the north region east of Puntan Sabaneta; segment densities ranged from 0 to 11.3 organisms 100 m<sup>-2</sup>.



**Figure 8.7.1m.** Densities (organisms 100 m<sup>-2</sup>) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted at Saipan during MARAMP 2003.

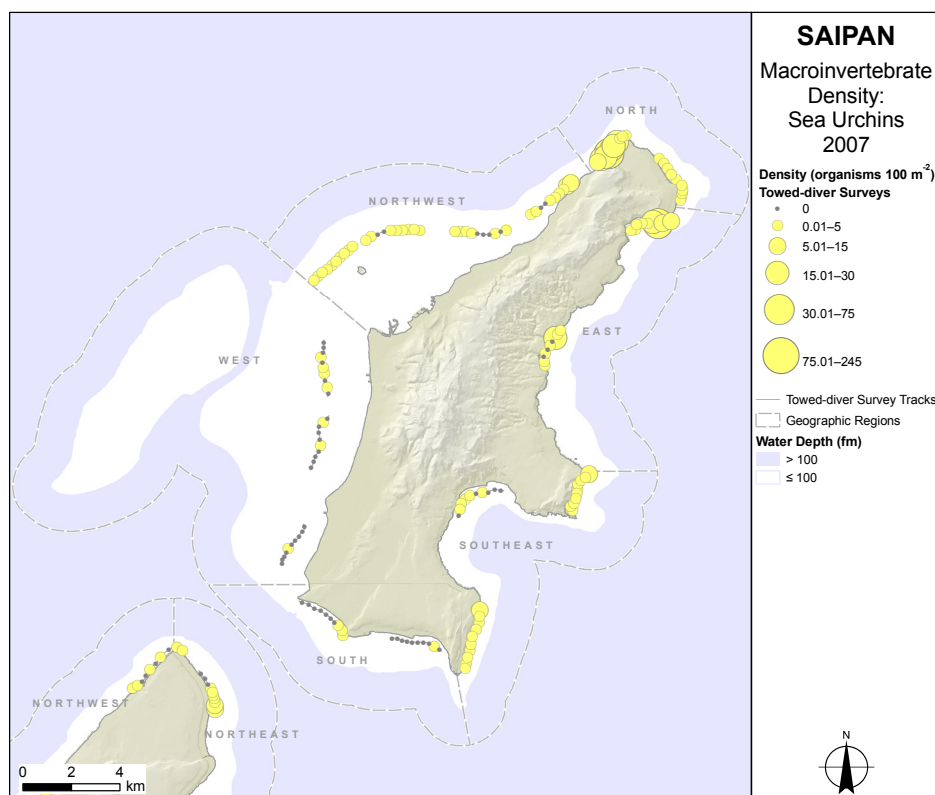
During MARAMP 2005, sea urchins were observed at 4 of the 8 REA sites surveyed and in 14 of the 17 towed-diver surveys conducted around Saipan (Fig. 8.7.1n). The overall mean density of sea urchins from REA surveys was 3.38 organisms 100 m<sup>-2</sup> (SE 1.66), and the islandwide mean density from towed-diver surveys was 2.36 organisms 100 m<sup>-2</sup> (SE 0.56). Survey results suggest sea urchins were most abundant at SAI-04, located in the northwest region north of Isleta Managaha, with a mean density of 12 organisms 100 m<sup>-2</sup>. Among all towed-diver surveys around this island, the survey completed around Puntan Sabaneta in the north region had the highest mean density of sea urchins with 19.84 organisms 100 m<sup>-2</sup>; segment densities from this survey ranged from 0 to 34.88 organisms 100 m<sup>-2</sup>. The second-greatest mean density of sea urchins from a towed-diver survey was 13.28 organisms 100 m<sup>-2</sup>, recorded between Puntans Dandan and I Naftan in the southeast region; segment densities ranged from 3.38 to 38.92 organisms 100 m<sup>-2</sup>. The third-greatest mean density was 3.84 organisms 100 m<sup>-2</sup>, recorded south of Puntan Makpe' in the northwest region; segment densities ranged from 0 to 21.02 organisms 100 m<sup>-2</sup>.

**Figure 8.7.1n.** Densities (organisms 100 m<sup>2</sup>) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted around Saipan during MARAMP 2005.



During MARAMP 2007, sea urchins were observed in all 16 of the towed-diver surveys conducted around Saipan (Fig. 8.7.1o) with an islandwide mean density of 2.3 organisms 100 m<sup>2</sup> (SE 0.47). Among all towed-diver surveys around this island, the survey completed near Puntan Sabaneta in the north region had the highest mean density of sea urchins with 15.37 organisms 100 m<sup>2</sup>; segment densities from this survey ranged from 2.66 to 38.66 organisms 100 m<sup>2</sup>. The

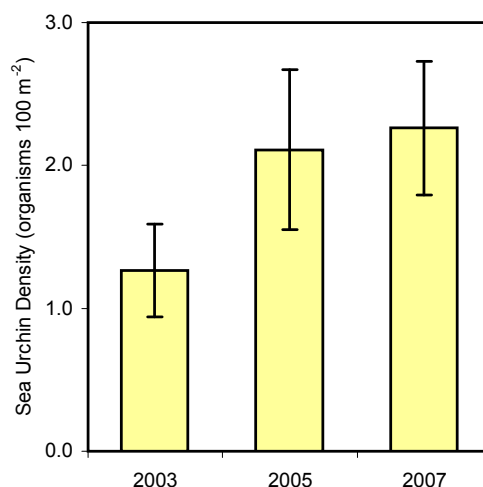
**Figure 8.7.1o.** Densities (organisms 100 m<sup>2</sup>) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted around Saipan during MARAMP 2007.





second-greatest mean density of sea urchins from a towed-diver survey was 9.12 organisms 100 m<sup>-2</sup>, recorded in Bahia Fanonchuluyan in the east region; segment densities ranged from 0.33 to 39.95 organisms 100 m<sup>-2</sup>. The third-greatest mean density of sea urchins was 2.12 organisms 100 m<sup>-2</sup>, recorded along Talofo'fo', Unai in the east region; segment densities ranged from 0 to 20.43 organisms 100 m<sup>-2</sup>.

Towed-diver surveys suggested low daytime abundance of sea urchins around Saipan, compared to the rest of the Mariana Archipelago, with the exception of the north coast stretching from Puntan Makpe' in the northwest region to Puntan Tangke in the east region. The overall observed mean density of sea urchins from towed-diver surveys was lower in 2003 than in 2007 (Fig. 8.7.1p). Minor fluctuations in densities are not necessarily indicative of changes in the population structure of sea urchins (For information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").



**Figure 8.7.1p.** Temporal comparison of mean densities (organisms 100 m<sup>-2</sup>) of sea urchins from towed-diver benthic surveys conducted on forereef habitats around Saipan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error ( $\pm 1$  SE) of the mean.

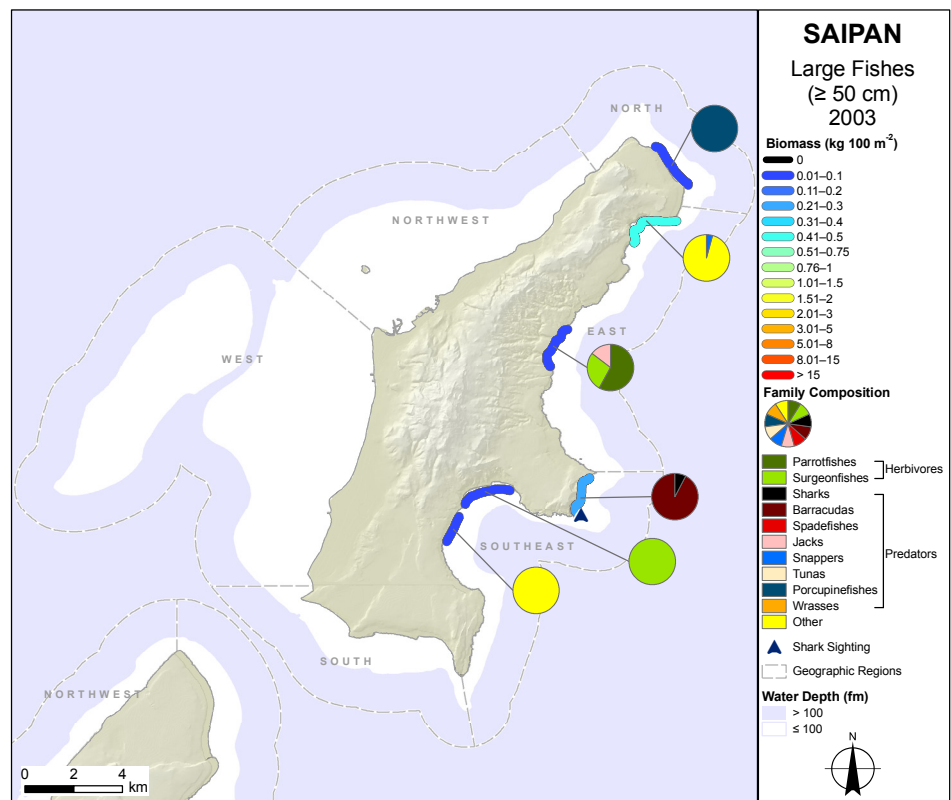
## 8.8 Reef Fishes

### 8.8.1 Reef Fish Surveys

#### *Large-fish Biomass*

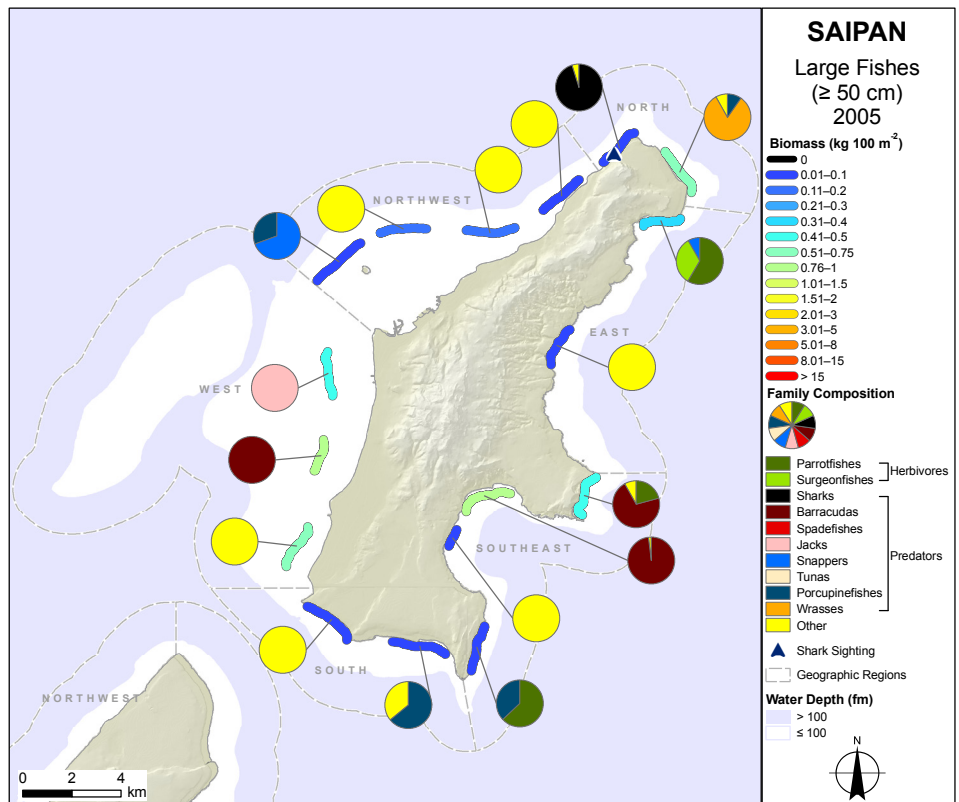
During MARAMP 2003, 6 towed-diver surveys for large fishes ( $\geq 50$  cm in total length [TL]) were conducted in forereef habitats at the island of Saipan. The overall estimated mean biomass of large fishes at this island, calculated as weight per unit area, was 0.13 kg 100 m<sup>-2</sup> (SE 0.06), a low value compared to other survey areas in the Mariana Archipelago. Since surveys were conducted only in the north, east, and southeast regions, it is not possible to discern any clear spatial patterns in the distribution of large-fish biomass (Fig. 8.8.1a). Stingrays accounted for the greatest proportion (51%) of overall mean large-fish biomass with a single porcupine ray (*Urogymnus africanus*) contributing 0.07 kg 100 m<sup>-2</sup> to overall mean large-fish biomass. Barracudas (Sphyraenidae) composed the second-greatest proportion (23%) or 0.03 kg 100 m<sup>-2</sup> of overall mean large-fish biomass. Surgeonfishes (Acanthuridae) and parrotfishes (Scaridae) were also common, accounting for 6% and 7% of overall large-fish biomass. The sleek unicornfish (*Naso hexacanthus*) was the major surgeonfish species by biomass, while the ember parrotfish (*Scarus rubroviolaceus*) was the major parrotfish species. Reef sharks (Carcharhinidae) were rarely encountered at Saipan, with a single grey reef shark (*Carcharhinus amblyrhynchos*) observed near Puntan Hakmang in the southeast region.

**Figure 8.8.1a.** Observations of large-fish ( $\geq 50$  cm in TL) biomass ( $\text{kg } 100 \text{ m}^{-2}$ ), family composition, and shark sightings from towed-diver fish surveys of forereef habitats conducted at Saipan during MARAMP 2003. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.



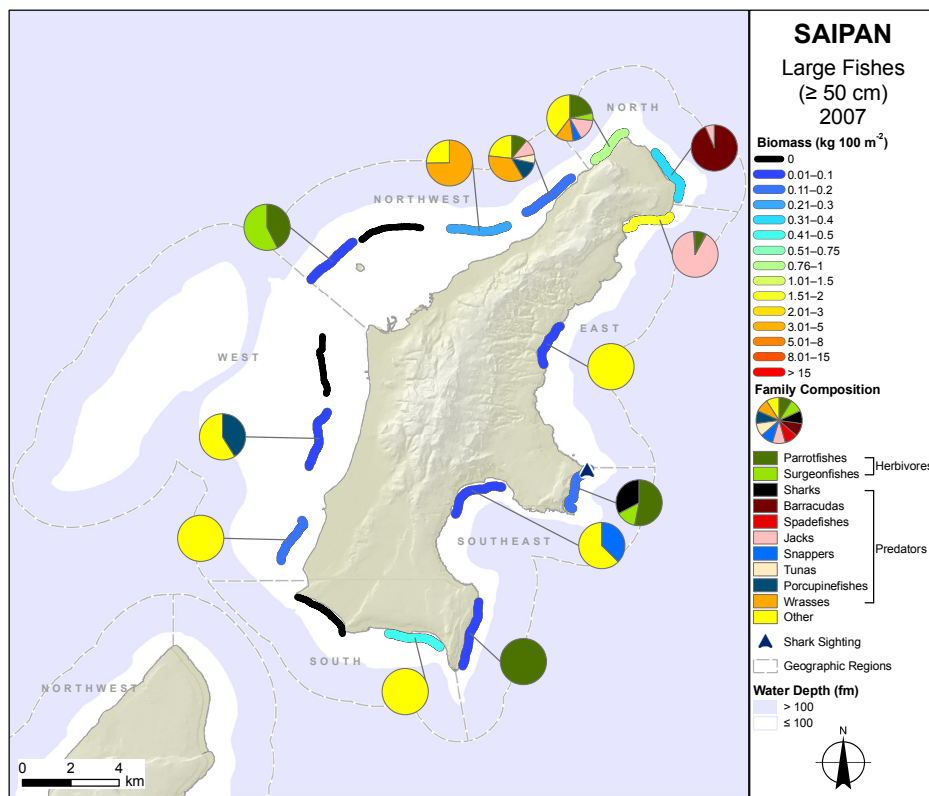
During MARAMP 2005, 17 towed-diver surveys for large fishes ( $\geq 50$  cm in TL) were conducted in forereef habitats around Saipan. The islandwide estimated mean biomass of large fishes was  $0.27 \text{ kg } 100 \text{ m}^{-2}$  (SE 0.07), a moderate value compared to other survey areas in the Mariana Archipelago but higher than the biomass observed at Saipan in 2003. Biomass values for large fishes were highest in the west region (Fig. 8.8.1b). Barracudas accounted for the greatest proportion (43%) or

**Figure 8.8.1b.** Observations of large-fish ( $\geq 50$  cm in TL) biomass ( $\text{kg } 100 \text{ m}^{-2}$ ), family composition, and shark sightings from towed-diver fish surveys of forereef habitats conducted around Saipan during MARAMP 2005. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.



0.11 kg 100 m<sup>-2</sup> of islandwide large-fish biomass, with a school of Heller's barracuda (*Sphyræna helleri*) contributing 84% of barracuda biomass. Jacks (Carangidae) composed the second-greatest proportion (10%) of overall large-fish biomass, which was entirely made up by a single school of snubnose pompano (*Trachinotus blochii*) observed during one survey. A single blacktip reef shark (*Carcharhinus melanopterus*) was the only shark observed during towed-diver surveys in 2005.

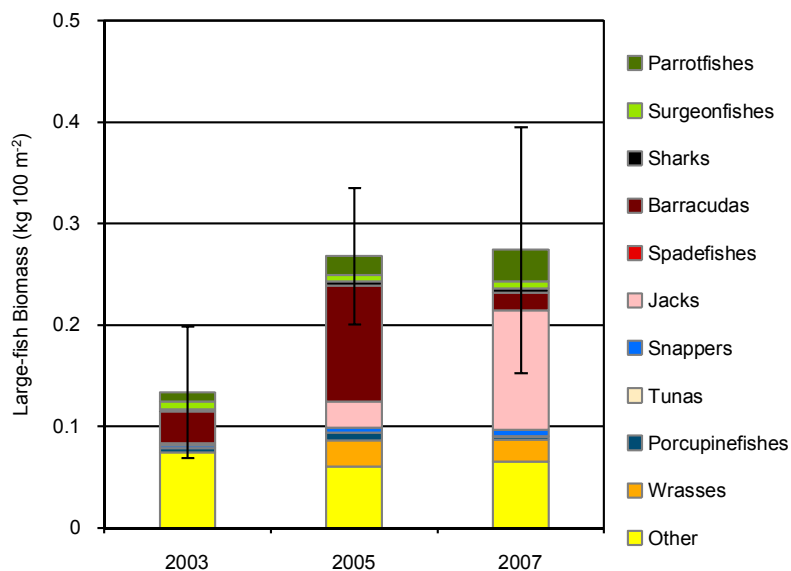
During MARAMP 2007, 16 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats around Saipan. The islandwide estimated mean biomass of large fishes was 0.27 kg 100 m<sup>-2</sup> (SE 0.12), a moderate value compared to other survey areas in the Mariana Archipelago but similar to the biomass observed around Saipan in 2005. Biomass values for large fishes were highest in the east and north regions (Fig. 8.8.1c). Jacks accounted for the greatest proportion (43%) or 0.12 kg 100 m<sup>-2</sup> of islandwide mean large-fish biomass. The bigeye trevally (*Caranx sexfaciatus*) was the most abundant jack species with a large school observed in the west region. Parrotfishes, wrasses (Labridae), and barracudas were also common, contributing 11%, 8%, and 6% of overall large-fish biomass. The ember parrotfish and the steephead parrotfish (*Chlorurus microrhinos*) were the 2 most abundant parrotfishes in terms of biomass. Near Puntan Laolao Kattan in the southeast region, 1 blacktip reef shark was observed.



**Figure 8.8.1c.** Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m<sup>-2</sup>), family composition, and shark sightings from towed-diver fish surveys of forereef habitats conducted around Saipan during MARAMP 2007. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.

Large-fish biomass from towed-diver surveys of forereef habitats at Saipan was lower during MARAMP 2003 than in subsequent survey periods (Fig. 8.8.1d). This temporal pattern could be a consequence of differences in survey effort and location: only 6 surveys were completed in 2003 and only in the north, east, and southeast regions. During MARAMP 2005 and 2007, islandwide mean large-fish biomass was similar at 0.27 kg 100 m<sup>-2</sup>; a value close to the average for the 4 southern, populated islands of the Mariana Archipelago. Barracudas, jacks, and parrotfishes contributed large proportions of large-fish biomass around Saipan; however, no single species consistently accounted for a majority of this biomass. Reef shark sightings were infrequent, with only 1 sighting recorded per survey period.

**Figure 8.8.1d.** Temporal comparison of mean values of large-fish ( $\geq 50$  cm in TL) biomass ( $\text{kg } 100 \text{ m}^{-2}$ ) from towed-diver fish surveys of forereef habitats conducted around Saipan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error ( $\pm 1$  SE) of the mean.

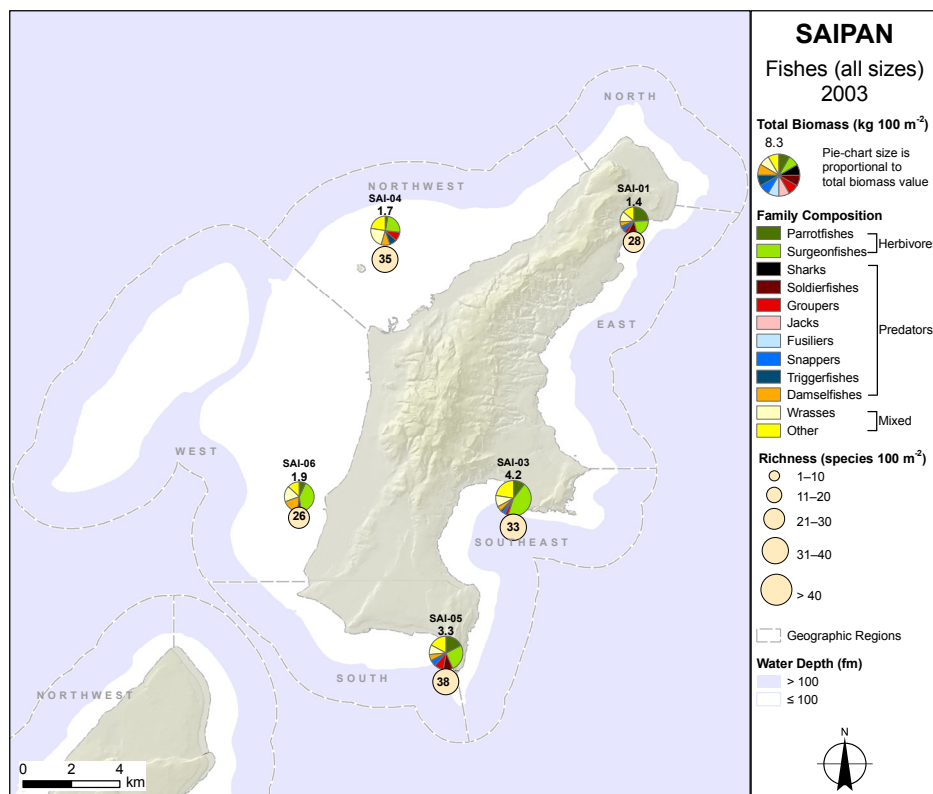


### Total Fish Biomass and Species Richness

Total fish biomass for the 5 REA sites surveyed in forereef habitats at Saipan during MARAMP 2003 was low, compared to other sites in the Mariana Archipelago, with an overall sample mean of  $2.51 \text{ kg } 100 \text{ m}^{-2}$  (SE 0.53). The highest biomass of  $4.18 \text{ kg } 100 \text{ m}^{-2}$  was observed at SAI-03 in the southeast region (Fig. 8.8.1e). Surgeonfishes accounted for the largest proportion (33%) or  $0.84 \text{ kg } 100 \text{ m}^{-2}$  of total fish biomass at Saipan. The 3 major species in terms of biomass in 2003 were the brown surgeonfish (*Acanthurus nigrofusus*), striated surgeonfish (*Ctenochaetus striatus*) and orangespine unicornfish (*Naso lituratus*). Wrasses and parrotfishes were also common, accounting for 13% and 12% of total fish biomass. No reef sharks were observed during these site-specific fish surveys in 2003.

Based on REA surveys conducted during MARAMP 2003, species richness at Saipan was relatively moderate with a range of 26–38 species  $100 \text{ m}^{-2}$ . The lowest diversity was seen at SAI-06 in the west region, and the highest diversity was found at

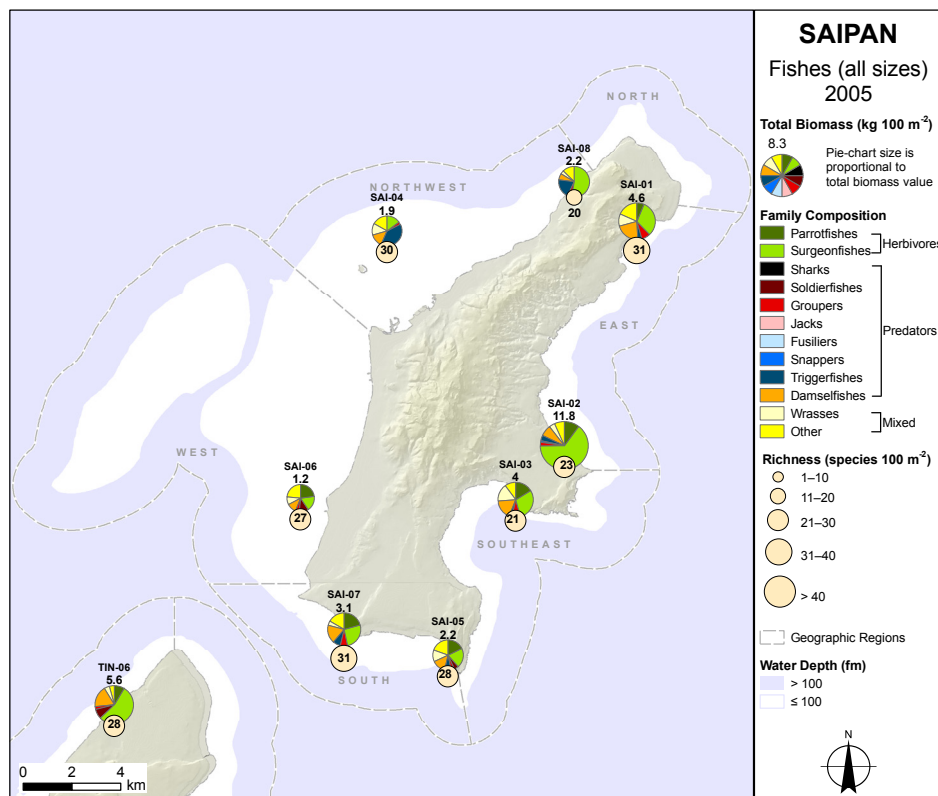
**Figure 8.8.1e.** Observations of total fish biomass (all species and size classes in  $\text{kg } 100 \text{ m}^{-2}$ ), family composition, and species richness (species  $100 \text{ m}^{-2}$ ) from REA fish surveys using the belt-transect method in forereef habitats at Saipan during MARAMP 2003.



SAI-05 in the south region (Fig. 8.8.1e). Wrasses were observed in the greatest diversity with 23 species recorded in 2003. Katherine's wrasse (*Cirrhitilabrus katherinae*) was the most abundant wrasse species. Damsel-fishes (Pomacentridae) were the most abundant fish taxa overall with the reticulate dascyllus (*Dascyllus reticulatus*) dominating counts with an overall mean density of 34 individuals 100 m<sup>-2</sup>.

Total fish biomass for the 8 REA sites surveyed in forereef habitats around Saipan during MARAMP 2005 was low, compared to other sites in the Mariana Archipelago, with an overall sample mean of 3.86 kg 100 m<sup>-2</sup> (SE 1.20). The highest biomass of 11.76 kg 100 m<sup>-2</sup> was observed at SAI-02 in the east region (Fig. 8.8.1f). Surgeonfishes accounted for the largest proportion (42%) or 1.64 kg 100 m<sup>-2</sup> of total fish biomass around Saipan with the orangespot surgeonfish contributing 45% of surgeonfish biomass. No large, predatory species, such as jacks and reef sharks, were observed during these site-specific fish surveys in 2005.

Based on REA surveys conducted during MARAMP 2005, species richness around Saipan was moderate and slightly lower than levels observed in 2003 with a range of 20–31 species 100 m<sup>-2</sup>. The lowest diversity was seen at SAI-08 in the northwest region, and the highest diversity was found at SAI-01 and SAI-07 in the east and south regions (Fig. 8.8.1f). Consistent with observations made in 2003, wrasses were the most diverse family with 26 species recorded around Saipan in 2005. The ornamented wrasse (*Halichoeres ornatissimus*) was the most abundant wrasse species. Damsel-fishes were the most abundant taxa of fishes overall with the ocellate damselfish (*Pomacentrus vaiuli*) dominating counts with an overall mean density of 47 individuals 100 m<sup>-2</sup>.



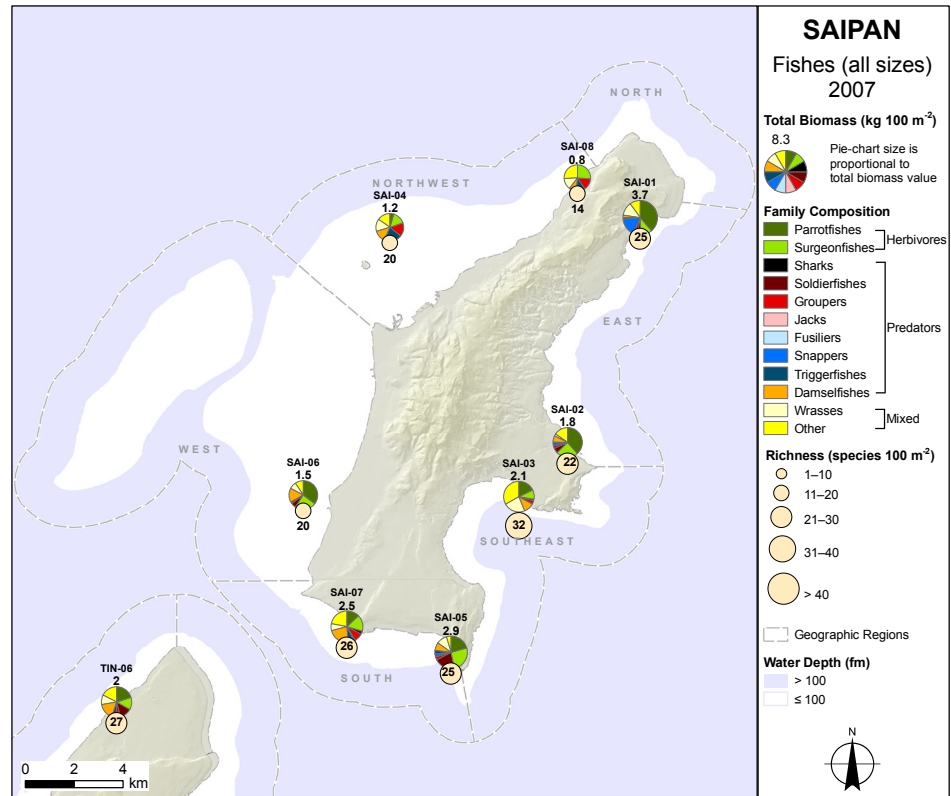
**Figure 8.8.1f.** Observations of total fish biomass (all species and size classes in kg 100 m<sup>-2</sup>), family composition, and species richness (species 100 m<sup>-2</sup>) from REA fish surveys using the belt-transect method in forereef habitats around Saipan during MARAMP 2005.

Total fish biomass for the 8 REA sites surveyed in forereef habitats around Saipan during MARAMP 2007 was low, compared to other sites in the Mariana Archipelago, with an overall sample mean of 2.07 kg 100 m<sup>-2</sup> (SE 0.33). The highest biomass of 3.66 kg 100 m<sup>-2</sup> was found at SAI-01 in the east region (Fig. 8.8.1g). Parrotfishes and surgeonfishes contributed most to biomass: 24% and 18%, respectively. The ember parrotfish accounted for the greatest proportion (37%) of parrotfish biomass, while the striated surgeonfish (*Ctenochaetus striatus*) contributed the greatest proportion (36%) of surgeonfish biomass. Similar to observations made in 2003 and 2005, no large, predatory species such as jacks and reef sharks were observed during these site-specific fish surveys in 2007.



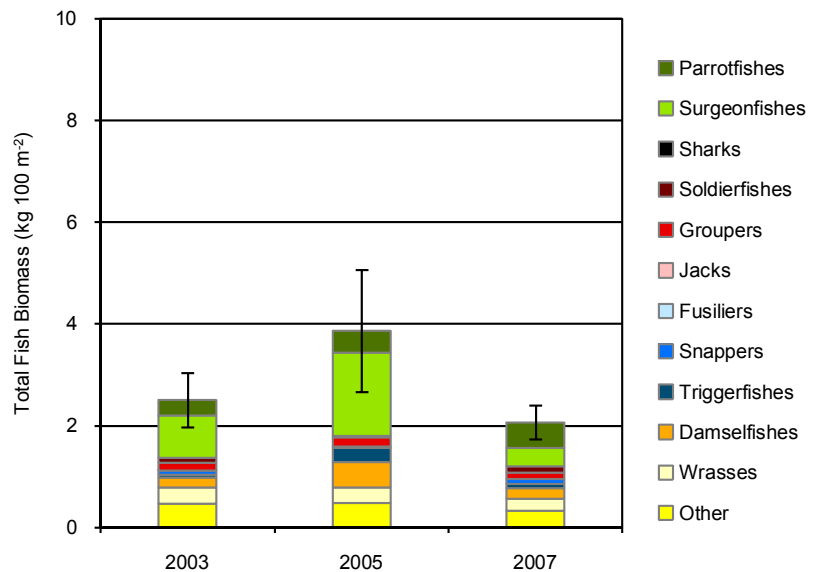
Based on REA surveys conducted during MARAMP 2007, species richness around Saipan varied among REA sites with a range of 14–32 species 100 m<sup>2</sup>. The lowest diversity was seen at SAI-08 in the northwest region, while the highest diversity was found at SAI-03 in the southeast region (Fig. 8.8.1g). Wrasses were again the most diverse family with 27 species recorded around Saipan in 2007. The red-lined wrasse (*Halichoeres biocellatus*) was the most abundant wrasse species. Damselishes dominated counts, and the ocellate damselfish was the most abundant damselfish species with an overall mean density of 24 individuals 100 m<sup>2</sup>.

**Figure 8.8.1g.** Observations of total fish biomass (all species and size classes in kg 100 m<sup>-2</sup>), family composition, and species richness (species 100 m<sup>-2</sup>) from REA fish surveys using the belt-transect method in forereef habitats around Saipan during MARAMP 2007.



During MARAMP 2005 and 2007, total fish biomass in forereef habitats around Saipan was marginally higher in the east region, and in 2003 the highest biomass was observed in the southeast region. As with the other southern islands in the Mariana Archipelago, the dominant families for the 3 MARAMP survey years were surgeonfishes, wrasses, and parrotfishes. Total fish biomass remained fairly consistent from MARAMP 2003 to 2007 (Fig. 8.8.1h) with a mean across the 3

**Figure 8.8.1h.** Temporal comparison of mean values of total fish biomass (all species and size classes in kg 100 m<sup>-2</sup>) from REA fish surveys of forereef habitats conducted around Saipan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error ( $\pm 1$  SE) of the mean.



years of 2.81 kg 100 m<sup>-2</sup> (SE 0.54), a value only slightly higher than the lowest average for the Mariana Archipelago, which was recorded around Guam.

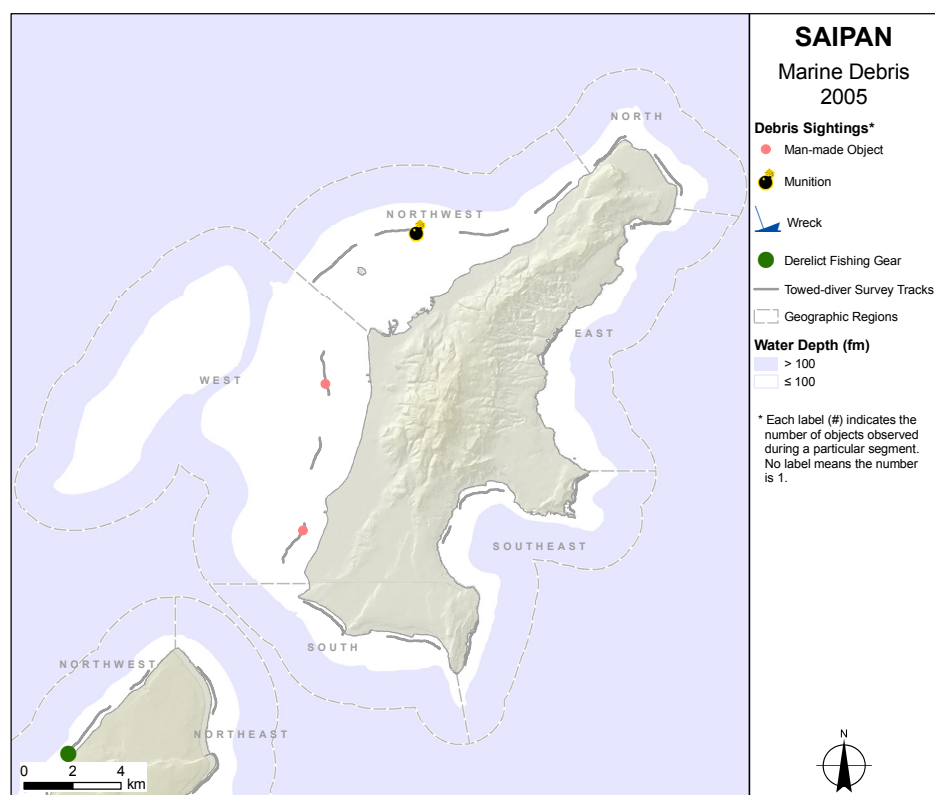
Species richness at Saipan was highest during MARAMP 2003 with 32 species 100 m<sup>-2</sup> and declined to 26 and 23 species 100 m<sup>-2</sup> during MARAMP 2005 and 2007. A similar pattern was seen around Tinian but not at other islands. The reasons for this apparent decrease in species richness around Saipan are not clear. Overall, species richness around Saipan during all MARAMP surveys was 27 species per 100 m<sup>-2</sup>, a level comparable to values observed around Tinian and much higher than the diversity seen around Guam. Wrasses were consistently the most diverse family with an average of 25 species observed over the 3 MARAMP survey years. Damselfishes were the most abundant taxa of fishes overall and dominated counts in each of the 3 survey periods.

## 8.9 Marine Debris

### 8.9.1 Marine Debris Surveys

During MARAMP 2003, no sightings of marine debris were recorded in the 6 towed-diver surveys conducted on forereef habitats at the island of Saipan.

During MARAMP 2005, 1 piece of unexploded munition and 2 sightings of other man-made objects were recorded in the 17 towed-diver surveys conducted on forereef habitats around Saipan (Fig. 8.9.1a). In the west region, 1 pipe that hosted a large amount of coral growth was noted south of Puntan Susupi (for place-names and their locations, see Fig. 8.2a in Section 8.2: “Survey Effort”). A mooring anchor consisting of a toppled block with ground tackle was observed in the northern part of Garapan Anchorage. Finally, a munition was observed northeast of Isleta Managaha in the northwest region. This munition site appears to be well known, as it is marked on readily available NOAA charts. No derelict fishing gear or wrecks were identified.

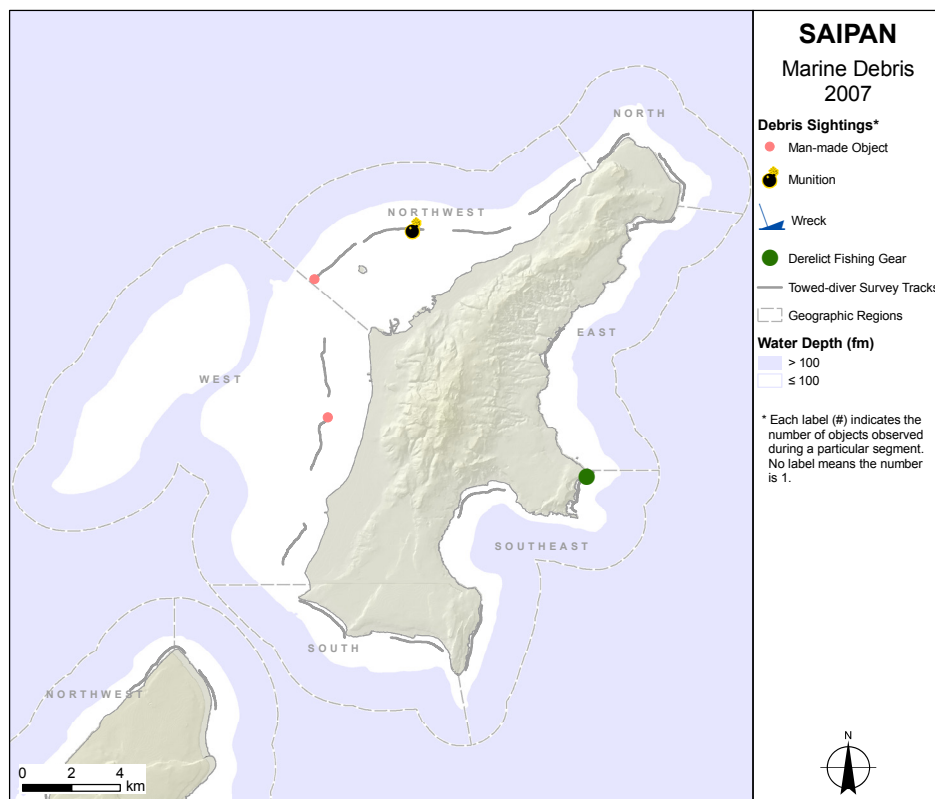


**Figure 8.9.1a.** Qualitative observations of marine debris from towed-diver benthic surveys of forereef habitats conducted around Saipan during MARAMP 2005. Symbols indicate the presence of specific debris types.

During MARAMP 2007, 1 sighting of derelict fishing gear, 1 munition sighting, and 2 sightings of other man-made objects were recorded in the 16 towed-diver surveys conducted on forereef habitats around Saipan (Fig. 8.9.1b). A fishing net was seen near Puntan Laolao Kattan in the southeast region. The 2 sightings of man-made objects were an anchor in the

west region adjacent to Lagunan Garapan and a mooring, including a ball and line, in the northwest region. As in previous MARAMP survey years, a munition sighting was recorded in the northwest region northeast of Isleta Managaha. No wrecks were identified.

**Figure 8.9.1b.** Qualitative observations of marine debris from towed-diver benthic surveys of foreereef habitats conducted around Saipan during MARAMP 2007. Symbols indicate the presence of specific debris types.



Observations of debris are positive identifications, but absence of reports does not imply lack of debris. Since methods for observing marine debris varied between MARAMP surveys in 2003, 2005, and 2007, temporal comparisons are not appropriate. Debris sightings were recorded differently—with sightings in 2003 recorded as a direct part of diver observational methods and sightings in 2005 and 2007 recorded solely as incidental observations by the towed divers in their observer comments. Still, the location of the munition sighting in the northwest region, northeast of Isleta Managaha, was the same in 2005 and 2007.

## 8.10 Ecosystem Integration

The spatial distributions and temporal patterns of individual coral reef ecosystem components around the island of Saipan are discussed in the discipline-specific sections of this chapter. In this section, key ecological and environmental aspects are considered concurrently to identify potential relationships between various ecosystem components. Biological information from towed-diver surveys was integrated to derive 3 composite indices that provide assessments of the relative ecological conditions of foreereef habitats in the 4 populated, southern islands of Saipan, Tinian, Rota, and Guam.

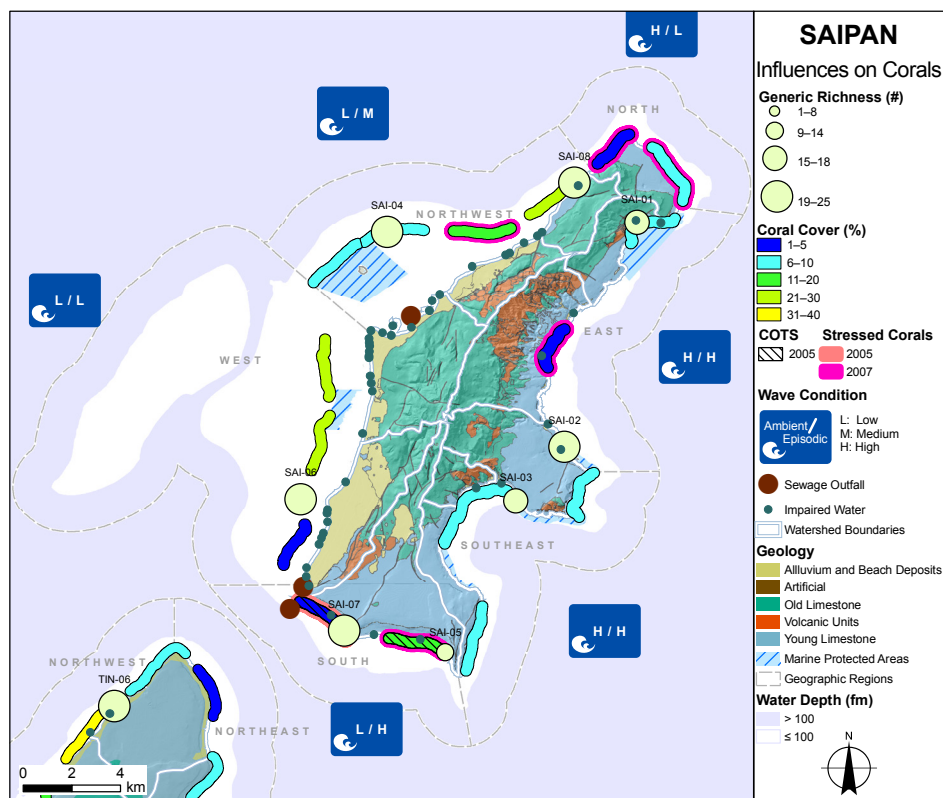
The *Benthic Condition Index for Guam, Rota, Tinian, and Saipan* was derived by equally weighting observations of the following 5 parameters from towed-diver benthic surveys around these 4 islands: cover of live hard corals, stressed corals, macroalgae, and crustose coralline red algae and density of (COTS). The *Fish Condition Index for Guam, Rota, Tinian, and Saipan* was derived from 2 equally weighted parameters from towed-diver fish surveys: density and biomass of large fishes ( $\geq 50$  cm in TL). The overall *Coral Reef Condition Index for Guam, Rota, Tinian, and Saipan* was derived from an equal weighting of these benthic and fish indices. These condition indices were calculated using ranks assigned to the biological variables from towed-diver surveys conducted around Saipan, relative to all surveys performed around the 4 populated, southern islands of Saipan, Tinian, Rota, and Guam for each survey year. To indicate changes in these ranks between survey years, these indices were visualized on a map within survey areas, which are represented by color-coded

and irregular polygonal buffers derived from towed-diver-survey tracks that overlapped in 2005 and 2007 (towed-diver-survey tracks were often similar but not exactly the same in each survey year). For more details about the methodology behind these indices, see Chapter 2: “Methods and Operational Background,” Section 2.5: “Ecosystem Integration.” Each of these 3 condition indices is presented for Saipan on a map in Figure 8.10b. Reef condition indices for the entire Mariana Archipelago are presented in Chapter 3: “Archipelagic Comparisons,” providing ranks for Saipan as well as the other 13 islands covered in this report.

### Comparison of Western and Eastern Habitats

The distribution of anthropogenic pressures around Saipan shows an east–west gradient, with the highest levels of human activities with the potential to affect coral ecosystems occurring along the west coast of Saipan. The majority of the resident population of Saipan is located on the west coast, and this shoreline also has the most intensive tourist development with associated recreational activities, such as scuba diving and water sports (Fig. 8.1.2a in Section 8.1.2: “Land Use”). In addition, locations along the west coast have suffered from water-quality issues because of point source pollution, from sources such as sewage outfalls and discharge of hypersaline and nutrient-enriched wastewater from reverse osmosis units used by some facilities that cater to tourists, and because of nonpoint source pollution like runoff during storms (Starmer et al. 2005). The CNMI beach water-quality monitoring program revealed that many beach locations within the Lagunan Garapan (from Puntan Achugao south to Puntan Susupi), and to a lesser extent locations on the southwest coast, failed to meet required water-quality standards. In most cases, elevated bacterial levels were thought to be associated with sewage system failures, which could also result in the delivery of high levels of nutrients to lagoon waters (Bearden et al. 2008).

Despite the apparent anthropogenic impacts occurring on the west side of Saipan, the distribution of live hard corals around this island suggests that, in general, average coral cover was higher on western forereef habitats than on eastern habitats (Fig. 8.10a). Mean cover of live corals for the northwest and west regions was 18% and 14% in 2005 and 2007, compared with a mean of 5% and 7% for all other regions. Results from 3 towed-diver surveys stand out as having the highest levels of coral cover at Saipan. One survey, located in the northwest region just south of Puntan Makpe', characterized the benthos as moderately sloped, continuous reef of medium complexity. The other 2 surveys, conducted in the northern part of the west region parallel to the Lagunan Garapan, recorded medium complexity continuous reef, which shifted to medium-low complexity patch reefs as surveys progressed from south to north.



**Figure 8.10a.** Cover (%) observations of live and stressed corals from towed-diver surveys and generic richness from REA surveys conducted on forereef habitats around Saipan during MARAMP 2005 and 2007, presented with geology, watersheds, impaired water sites, and other factors (Caruth 2003; M Pangelinan, CNMI Department of Land and Natural Resources, pers. comm.; Bearden et al. 2008). Values of coral cover and generic richness represent averages of data from both survey years, where available; otherwise values represent data from the single year surveyed. Towed-diver-survey areas combine overlapping survey tracks for both MARAMP survey years. Colored outlines represent areas where estimates of stressed-coral cover were > 10%, and diagonal lines indicate areas where COTS density was > 0.15 organisms 100 m<sup>-2</sup>. A large, blue icon indicates the level of ambient and episodic wave exposure for each geographic region.



Variation in the benthic communities at Saipan may be related to the different geological, topographic, and oceanographic characteristics of the 2 sides of Saipan. West of Saipan, the distribution of marine habitats is influenced by the presence of 2 extensive, shallow shelves. The most westerly of these shelves provides a shallow platform, located at depths of 30–40 m and covering an area of ~ 20 km<sup>2</sup>. This bank is surrounded by steep slopes that descend to > 200 m. The easterly shelf is located at depths of 20–40 m, covers an area of ~ 30 km<sup>2</sup>, and abuts the shallow Lagunan Garapan that runs along much of the southwestern coastline. This inner shelf continues around the rest of Saipan, albeit in much narrower form. In combination, these 2 shelf areas provide an extensive area of shallow, hard substrate suitable for coral reef development. In contrast, no such extensive shallow areas are present to the north, east, or south of Saipan. Where a shallow shelf is present, it is very narrow, increasing in width only within embayments. This pattern is highlighted in the map of benthic zones, which shows the lack of flat zones (Fig 8.3.1f in Section 8.3: “Benthic Mapping and Characterization”). South of Saipan, the seafloor slopes gradually to a depth of 50 m less than 1 km from the coast. Southeast of Saipan, the shelf is even narrower, with the edge lying at a depth of 20 m less than 300 m from the shore. East of Saipan, terraces at depths of 20 m and 30 m are within 300 m of the shore. North of Saipan, the shelf is slightly more extensive, with a series of terraces at depths of 20 m, 50 m, and 60 m. At the northern points of Saipan, these features extend a little farther from the coast (e.g., the terrace at a depth of 40 m is ~ 500 m offshore), forming submarine peninsulas with the terraced platforms reflecting previous sea levels. This lack of large shallow areas in these regions around Saipan limits the habitat suitable for reef development.

In addition to the reduced availability of suitable substrate for coral reef development, habitats east of Saipan are subject to greater exposure to wind and wave energy than are habitats in the west, both in terms of ambient wave energy and episodic high-energy events like typhoons (Fig. 8.10a). Some studies have suggested that high-energy environments can favor development of reefs with low coral cover dominated by small, robust colonies (Storlazzi et al. 2001).

Although levels of live coral cover were lower on forereef habitats east of Saipan than on habitats west of this island, the benthic communities in most survey areas appeared to be in good condition in 2007, with medium or high ranks for surveys in the east and southeast regions in the calculated *Benthic Condition Index* for Guam, Rota, Tinian, and Saipan (Fig. 8.10b). These ranks suggest that the relatively low coral cover in these areas may reflect the natural character of the reefs there, because of the geological, topographic, and oceanographic factors described previously, and may not result from human activities.

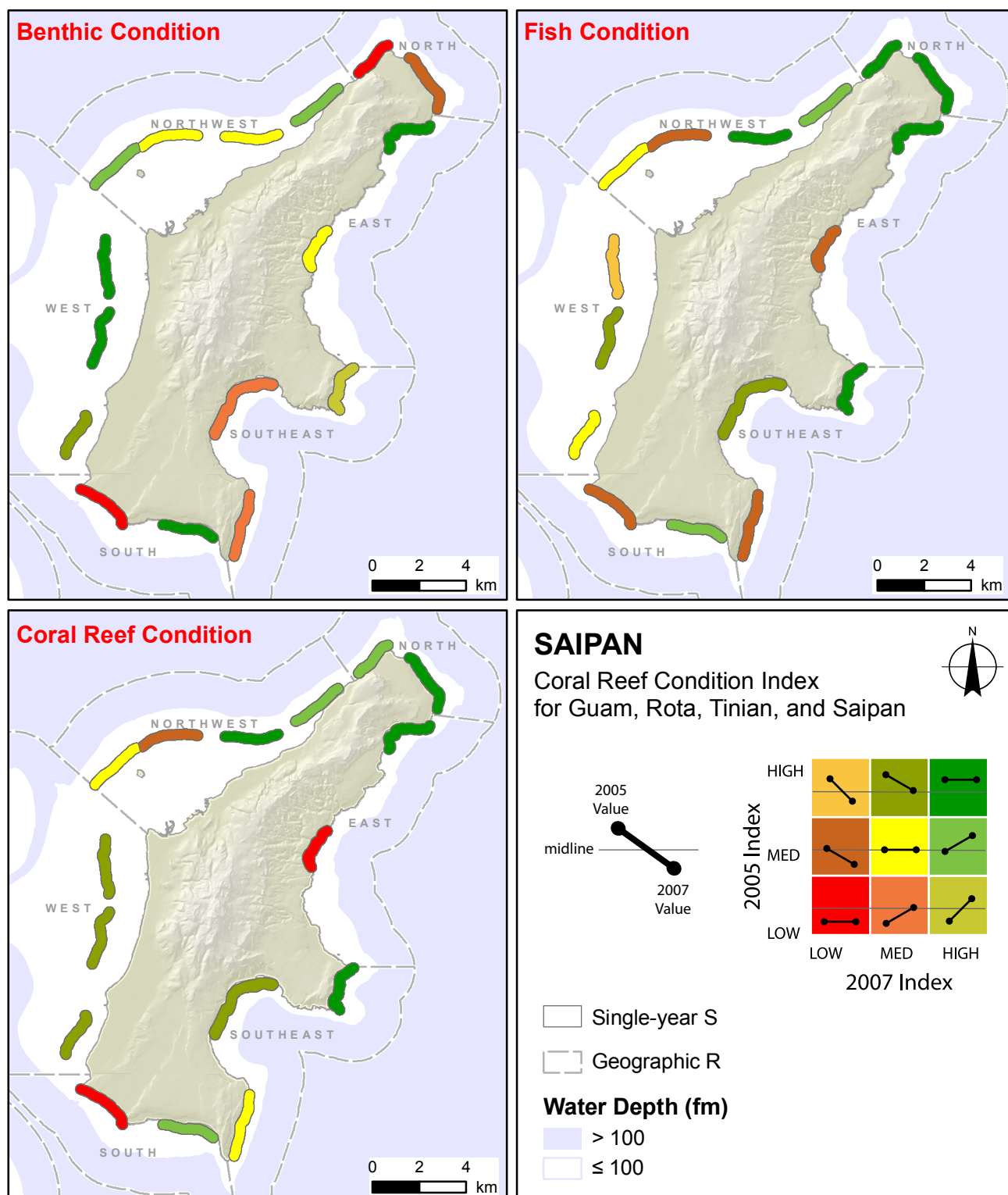
Similarly, the east–west pattern described previously did not appear to influence fish communities at Saipan, where survey results were mixed between survey locations, years, and techniques (Fig. 8.10c).

### **Garapan Anchorage**

The 2 extensive shelf areas are unique features to Saipan and form the Garapan Anchorage, which is an area of particular management interest because of the anticipated expansion of anchorage areas to support the proposed increase of military activity in the CNMI. Acoustic mapping of this area revealed an interesting topography on the bank tops, which are characterized by a complex mosaic of channels and mounds, interpreted to be coral mounds. At the request of the Department of Defense, CRED conducted additional surveys to provide a comprehensive map of areas of high coral cover or other biological significance. Extensive optical surveys using the TOAD were done, and their results were used to provide an interpolated map of live coral cover (Fig. 8.3.3c in Section 8.3: “Benthic Mapping and Characterization”) and locations of sand basins (Fig. 8.3.3a), covering the entire anchorage area. Results from both towed-diver surveys and analyses of TOAD video footage show an area of high coral cover along the eastern edge of the inner anchorage, adjacent to the Lagunan Garapan. These results also are illustrated in the *Coral Reef Condition Index* (Fig. 8.10b), analysis that highlights 2 towed-diver surveys completed along the edge of this lagoon. These 2 survey areas had high ranks in the *Benthic Condition Index* in both 2005 and 2007, a reflection of the high cover values for live corals and crustose coralline red algae, relative to cover levels for macroalgae.

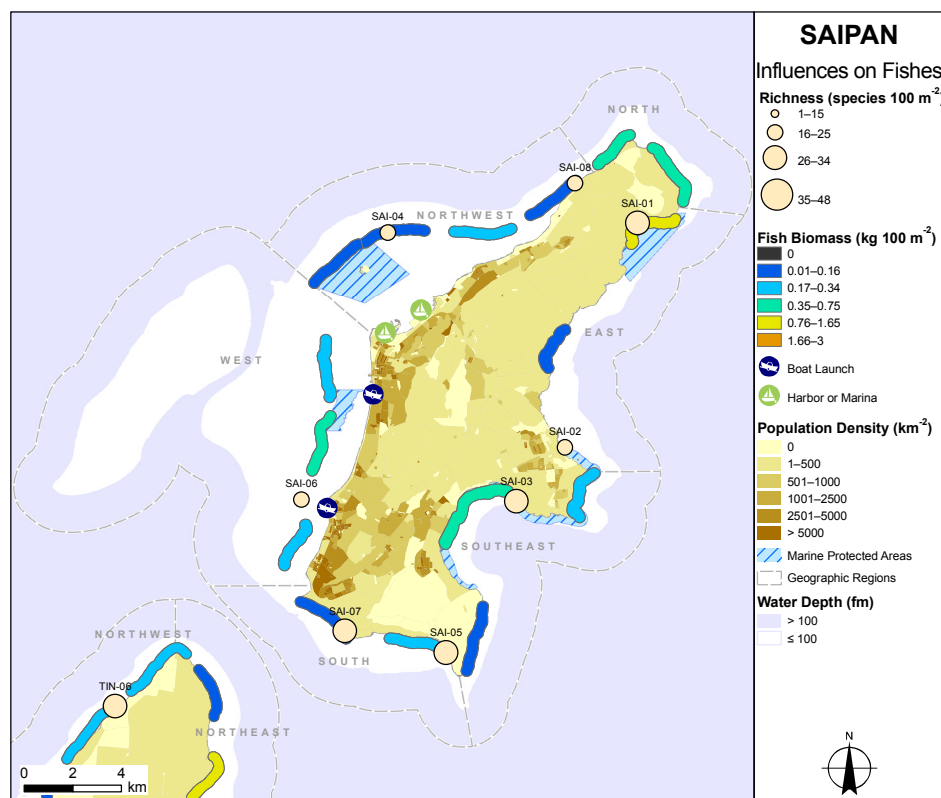
In addition to the numerous patches of high coral cover observed during towed-diver surveys in the inner anchorage area, analyses of video footage from TOAD surveys identified significant coral resources in deeper waters. The highest levels of live coral cover were recorded in the depth range of 61–70 m, at least as seen in a majority of images, with average cover of live corals > 60%. These data suggest the presence of important coral communities in both shallow and deep waters, and the value associated with the planning of future anchorage sites to minimize effects on coral reef ecosystems. These results highlight the importance of monitoring at the full range of depths in which coral communities may be present to ensure that managers of coral reef resources are informed of important mesophotic coral communities.





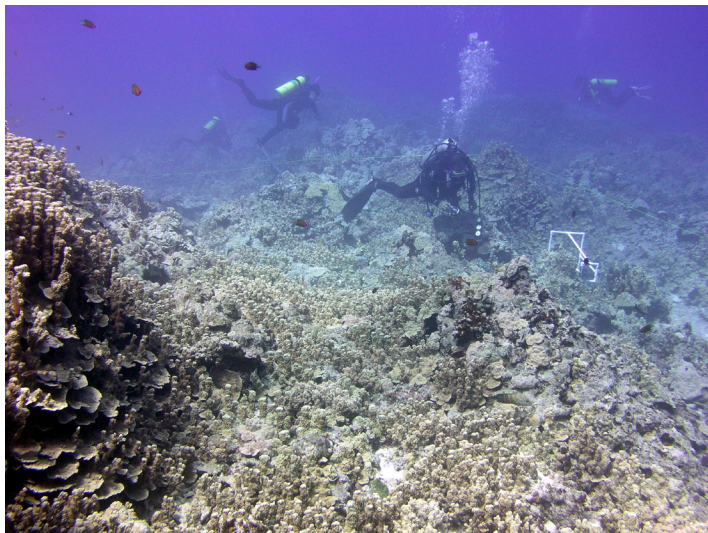
**Figure 8.10b.** The Coral Reef Condition Index for Guam, Rota, Tinian, and Saipan, as well as the associated Benthic Condition Index and Fish Condition Index, reflect the condition of the benthic and fish communities and their integrated ecosystem for each towed-diver-survey area, relative to other survey areas around the 4 populated, southern islands. These maps indicate changes in index ranks between MARAMP 2005 and 2007 for towed-diver-survey areas around Saipan. Survey areas are represented by irregular polygonal buffers derived from towed-diver-survey tracks that overlapped in 2005 and 2007. No index value is calculated for areas with only one year of survey data. A high rank means superior condition relative to other survey areas around the 4 populated, southern islands. The survey area along the northern coast of Saipan, for example, has a high rank for both 2005 (y-axis) and 2007 (x-axis) and, thus, is assigned the bright-green color that corresponds to the top-right square in the legend. The position of the horizontal bar above the midline in this square also reflects that this survey area maintained a high rank in both years.

**Figure 8.10c.** Observations of large-fish ( $\geq 50$  cm in TL) biomass ( $\text{kg } 100 \text{ m}^{-2}$ ) from towed-diver surveys and species richness from REA fish surveys conducted on forereef habitats around Saipan during MARAMP 2005 and 2007, presented over a map of human population density (U.S. Bureau of the Census 2003, 2008). Biomass and richness values represent averages of data from both survey years, but, if surveys were conducted during one year only, then values represent data from that single year. Towed-diver-survey areas combine overlapping survey tracks for both MARAMP survey years; survey tracks are often similar but not necessarily the same between survey years.



### **Bahia Laolao and Bird Island Sea Cucumber Reserve**

An area of particular interest in the southeast region is Bahia Laolao, also known as Laulau Bay. This area supported some of the highest levels of live coral cover recorded by towed divers in 2003. However, coral cover was generally recorded at the same low level observed elsewhere around Saipan in 2005 and 2007. Coral cover was 6%–10% from towed-divers surveys on either side of the Bay, a range similar to the islandwide means of 11% in 2005 and 10% in 2007.



**Figure 8.10d.** REA divers surveying *Porites rus*-dominant SAI-03 site. NOAA photo by Robert Schroeder

One segment of a towed-diver survey conducted in Bahia Laolao in 2007 recorded mean coral cover of 35% in an area notable for having the highest habitat complexity observed within this bay. Located ~ 600 m from this survey segment, REA site SAI-03 in 2007 had coral cover of 20%, one of the highest levels of coral cover recorded at Saipan REA sites (Fig. 8.10d). These results suggest a degree of local patchiness in the coral cover within this bay that is characterized by complex and varied habitats.

Overall, benthic conditions in Bahia Laolao were low in 2005, with low values of coral cover and high levels of macroalgal cover observed during

towed-diver surveys in some areas in this bay (Fig. 8.10a). Low densities of COTS were observed throughout the bay during the 3 MARAMP survey years, while cover of stressed corals was recorded at  $> 10\%$  in several segments of towed-diver surveys. High macroalgal cover was observed by towed divers during the 3 MARAMP survey years. In 2005, the highest macroalgal cover observed around Saipan was recorded south of Tuteuram, with a mean macroalgal cover of 69%, com-

pared to the islandwide mean of 31%. Finally, it is important to note that persistent, high macroalgal cover in Bahia Laolao was recorded during seasonal precipitation peaks (MARAMP 2003 and 2005) and lows (MARAMP 2007). Although it is hypothesized that high macroalgal cover indicates a degraded reef system in this area, if no historical records of high coral cover exist, it is not possible to determine with certainty that this area ever exhibited a high percentage of cover of hard coral species. High macroalgal cover may represent the natural state.

If high macroalgal cover is a recent development, it may be a result of water-quality issues that are known to affect this area. Poor water quality usually coincides with increased nutrients, which can favor the faster-growing algae over coral colonies in the competition for space. Independent surveys by the CNMI Department of Environmental Quality also have noted poor reef conditions in this area (Bearden et al. 2008). When examining oceanographic data collected by CRED through shallow-water ( $\leq 30$  m) CTD casts during MARAMP 2003, elevated temperatures were coupled against lower densities and salinities at sampling locations to the north and south of Bahia Laolao, versus results from other sampling locations at Saipan, possibly a result of terrigenous inputs associated with increased seasonal precipitation. Two shallow-water casts completed in 2007 along the interior of this bay yielded comparable results despite seasonally low precipitation. Additionally, strong tidal currents across the Mariana Ridge may cause mixing in the southeast and northeast regions around Saipan. This mixing may lead to some additional nutrient enrichment of surface waters in Bahia Laolao, relative to other areas around Saipan.

Bahia Laolao is a marine protected area, which was originally designated for the protection of sea cucumbers in 2000, following several years of over-harvesting (CNMI Public Law 11-63; Trianni 2000). Some of the highest densities of sea cucumbers observed during towed-diver surveys were recorded here in 2003. In contrast, towed-diver surveys in 2005 and 2007 recorded sea cucumber densities that were fairly low in comparison to results in other survey areas around Saipan. This decline could be a result of natural variation in the populations present, but because sea cucumbers are the focal species of this reserve, the apparent decline could be a potential cause for concern.

A second marine reserve designated in 2000 for the protection of sea cucumbers, the Bird Island Sea Cucumber Reserve is located in Bahia Fanonchuluyan in the northeast region. This sea cucumber reserve is nested within the larger Bird Island Marine Sanctuary, which was designated in 2001. The highest densities of sea cucumbers recorded at Saipan in 2005 and 2007 and the second-highest densities in 2003 were observed during towed-diver surveys in this bay. In both 2003 and 2007, the greatest densities recorded during REA benthic surveys were observed at SAI-01, also within Bahia Fanonchuluyan. Sea cucumbers were most commonly encountered in habitats of hard-substrate reef, with rubble and boulders, that also supported high numbers of sea urchins. Cracks and crevices within the reef matrix, coupled with areas of vertical walls increased localized habitat complexity. The high densities of sea cucumbers observed here relative to other parts of Saipan may be evidence of successful management actions to protect and recover this previously depleted resource.

### ***Crown-of-thorns Seastars***

During MARAMP 2005, towed-diver surveys recorded COTS in high abundance in the south region of Saipan with densities of up to 20 organisms  $100\text{ m}^{-2}$  (Fig. 8.10e). This region is an area of a potential outbreak, according to the definitions presented in Section 8.7: “Benthic Macro-invertebrates.” Towed-diver surveys in 2005 in the south region also recorded very low live coral cover, within a range of 0.1%–5% from the survey completed between Puntans Agingan and Opyan, where stressed-coral cover also was recorded, and within a range of 5.1%–30% from the survey completed between Puntans Opyan and I Naftan. Similar levels of coral cover were recorded during MARAMP 2007, except that values for stressed-coral cover were elevated between Puntans Opyan and I Naftan. However, few COTS were observed in 2007, in comparison with results from 2005, reflecting the extreme variability and potentially



**Figure 8.10e.** A COTS seen on a reef off southern Saipan. NOAA photo by Kevin Lino



cryptic nature of these organisms. Diver observations in this region also noted that COTS were seen in areas where the benthos was composed of large, flat pavement, an atypical environment for COTS, which are usually seen in areas with live or distressed corals. In areas where corals were observed, divers noted that corals were subject to a large amount of predation from COTS.

## 8.11 Summary

This section presents an overview of the status of coral reef ecosystems around the island of Saipan and some of the key natural processes and anthropogenic activities influencing them. MARAMP integrated ecosystem observations provide a broad range of information: bathymetry and geomorphology, oceanography and water quality, and biological observations of corals, algae, fishes, and benthic macroinvertebrates along forereef habitats around Saipan. Methodologies and their limitations are discussed in detail in Chapter 2: “Methods and Operational Background,” and specific limitations of the data or analyses presented in this Saipan chapter are included in the appropriate discipline sections. One noteworthy limitation, for example, is the focus of MARAMP observations on forereef habitats to the exclusion of the many shallow backreef flats around Saipan. Methods information and technique constraints should be considered when evaluating the usefulness and validity of the data and analyses in this chapter.

To simplify interpretation of ecosystem conditions around Saipan, a *Benthic Condition Index*, a *Fish Condition Index*, and an integrated *Coral Reef Condition Index* were developed to reflect ecosystem conditions at specific locations around Saipan, relative to locations around the 4 populated, southern islands of Guam, Rota, Tinian, and Saipan and based on MARAMP 2005 and 2007 surveys only (see Section 8.10: “Ecosystem Integration”). By synthesizing large amounts of complex, interdisciplinary information, these reef condition indices assist resource managers in identifying potential relationships between various ecosystem components. The conditions of the fish and benthic communities and the overall ecosystem around Saipan, relative to all the other islands in the Mariana Archipelago, are discussed in Chapter 3: “Archipelagic Comparisons.”

The following summary highlights key attributes of the coral reef ecosystems around Saipan (for place-names and their locations, see Fig. 8.2a in Section 8.2: “Survey Effort”):

- Saipan has 90% of the total CNMI population. As a result of the development and tourism on the west coast of Saipan, this area has suffered from water-quality problems.
- Two large, submerged, flat banks extend (1) ~ 10 km to the west of Saipan and (2) from the Saipan Harbor area in the north to the southern shore of this island. These 2 banks are used as the primary anchorage for commercial and military vessels in the CNMI.
- Only a few streams exist on Saipan, and they are located to the west of Okso` Talufo`fo and Okso` Achugao along the northeast coast of this island.
- Benthic habitats on the east coast of Saipan have a reduced availability of suitable substrate for coral reef development because of the absence of the broad shelves found along the west coast. Habitats east of Saipan also are exposed to considerable wind and wave energy.
- Wave model output shows typical trade wind swells from the north and east and high wave energy from storm tracks from the southeast.
- STR and satellite-derived (Pathfinder) SST data show that temperatures surpassed the bleaching threshold for a brief period in September 2006.
- Interestingly, results from towed-diver surveys show that mean cover of live hard corals was higher on the west coast of Saipan than in other areas around this island, despite anthropogenic impacts from resident populations and tourist visits. This pattern is likely a result of greater habitat availability for reef development and shelter from wave energy on the west coast.
- Overall mean coral-colony density for Saipan, based on REA surveys, was substantially higher in 2003 with

28.9 colonies m<sup>-2</sup> than in 2005 with 49 colonies m<sup>-2</sup>. This increase was observed at all 3 sites surveyed in these years and could be a result of recruitment, fragmentation of existing colonies, or both.

- The level of coral disease, recorded during REA surveys in 2007, was low around Saipan, compared to other surveyed areas in the Mariana Archipelago, with a mean overall prevalence of 0.4%. Coral bleaching was mild and localized with an overall mean prevalence around Saipan of only 0.03%; affected colonies were mainly observed in the west region. Stressed-coral cover, recorded during towed-diver surveys, was absent in 2003, low in 2005, and more widespread in 2007. High numbers of crown-of-thorns seastars (COTS), relative to other areas surveyed in the Mariana Archipelago, were observed during towed-diver surveys in 2003 and 2005. Localized areas that may have been undergoing an outbreak included areas near Puntans Laolao Kattan and Hakmang in the southeast region in 2003 and Puntans Unai Opyan and Agingan in the south region in 2005. However, by 2007, observed COTS densities were low in these areas.
- Three major coralline-algal diseases were recorded around Saipan in 2007: coralline lethal orange disease, coralline white band syndrome, and coralline cyanobacterial disease. Coralline lethal orange disease was the most numerous overall around Saipan.
- An area of high coral cover, compared to other areas surveyed at Saipan, was recorded by towed divers on the east side of the inner bank of Garapan Anchorage. In the *Benthic Condition Index* for Guam, Rota, Tinian, and Saipan, the edge of this lagoon had a high rank in both 2005 and 2007. Results from analyses of TOAD video footage suggest that live coral cover was > 60% at depths of 61–70 m around this anchorage area. This area is of particular interest because of the anticipated expansion of anchorage areas with the proposed increase in military activity in the CNMI.
- Densities of giant clams were generally low at Saipan during all survey years, compared to results for the rest of the Mariana Archipelago. Abundance was greatest along the eastern half of Saipan. Sea cucumbers and sea urchins were fairly ubiquitous around this island during all years.
- Areas with high macroalgal cover, relative to other survey areas in the Mariana Archipelago, were recorded during towed-diver surveys in all 3 MARAMP survey years. In 2003, in the north region east of Puntan Sabaneta, macroalgal cover was 76%. In 2005, macroalgal cover was highest (69%) in the southern part of Bahia Laolao in the southeast region, and, in 2007, northwest of Isleta Managaha in the northwest region, macroalgal cover was 68%. The highest cover of crustose coralline red algae (> 20%) from towed-diver surveys at Saipan was in Bahia Fanonchuluyan in the east region in 2003 and 2007 and off Isleta Managaha in 2005 and 2007.
- Bahia Laolao had relatively low coral cover, compared to the rest of the Mariana Archipelago, over the 3 MARAMP survey periods, as well as high macroalgal cover, giving it a low rank in the *Benthic Condition Index*. This bay has been known to have poor water quality. An area of mass wasting (landslides and erosion) is located in the center of this bay. Bahia Laolao is a marine protected area for sea cucumbers; however, densities there were low, compared to densities recorded in other regions, in 2005 and 2007, a condition that may be a cause for concern for local managers.
- Bird Island Sea Cucumber Reserve, located in Bahia Fanonchuluyan on the northeast coast of Saipan, is also a marine protected area for sea cucumbers. This area had the highest densities of sea cucumbers around this entire island in 2005 and 2007 and the second-highest densities in 2003, suggesting successful management of this previously depleted fishery.
- Large-fish biomass at Saipan, based on towed-diver surveys, was low in 2003 and moderate in 2005 and 2007, relative to other areas surveyed in the Mariana Archipelago. Biomass of large fishes in 2005 was greater in the west region than in other regions, although moderate large-fish biomass was observed in Bahia Laolao and along the northern tip of Saipan. Surveys in the west region in 2007 recorded very low biomass, compared to other regions, with either no or only a few individual fishes observed per survey. In 2007, the greatest large-fish biomass was observed during a survey in the north region southwest of Puntan Sabaneta. Similarly, compared to REA survey results at other islands of the Mariana Archipelago, total fish biomass was low and species richness was moderate for Saipan in all MARAMP survey years.



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